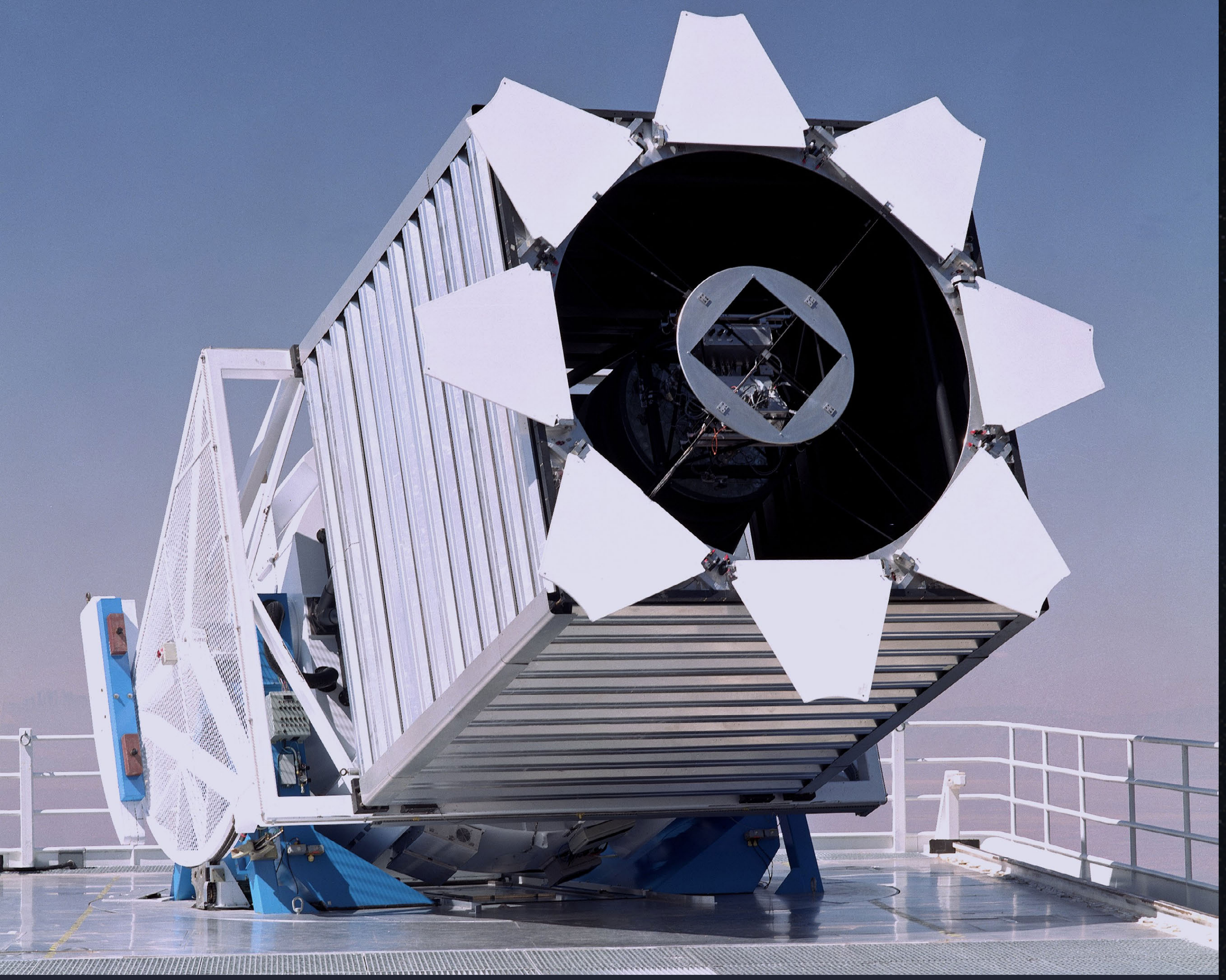

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click here for version check.

Interpreting SDSS extragalactic data in the era of JWST

Alexander Franklin Mayer

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SensibleUniverse.net

一鳴驚人

This is not a slide presentation— it is a self-study *digital monograph* in full-HD format that has many advantages over conventional publishing formats.

Anticipate *unprecedented* widespread cognitive dissonance.

Cognitive dissonance is the mental stress experienced by an individual who is confronted by new information that conflicts with existing beliefs or ideas. People with weak constitutions or having narcissistic tendencies are motivated to avoid, disregard, or disparage information that is likely to increase it.

“It is the scientist’s duty to attempt to disprove his conjectures” (K. Popper), thus a fundamental characteristic of a competent professional scientist is the ability to deal with the mental stress that accompanies the falsification of a theory associated with current and past work, just as an aviator must occasionally deal with the stress of a major malfunction (e.g., 2010 Hudson River landing by Capt. C. ‘Sully’ Sullenberger). *The point is that we want everybody to handle the situation, and come out OK.*

The paradigm shift instigated by the following new scientific information is of an unprecedented scope, and it is certain to induce acute stress in a significant number of individuals, abruptly and simultaneously. Accordingly, some academic institutions may find it prudent to plan for related professional counseling in a group setting, as this work is certain to have profound emotional as well as scientific impact.

NTSB/AAR-10/03

The canonical fundamentals

ca•non•i•cal (adjective) : according to recognized rules or scientific laws [historically, often completely wrong].

- The most fundamental assumption of the Big Bang theory is that the observed cosmological redshift of galaxies is caused by the *uniform expansion of space*.
- Such an expansion would cause the space between galaxies to increase over time, which corresponds to a modeled general *recessional velocity* between galaxies.
- The wavelength of a receding light source is broadened towards the red end of the visible spectrum in proportion to recession velocity, and similarly by the modeled uniform expansion of space during propagation; *redshift* is a dimensionless quantity designated by z and applicable to photons of any source wavelength.
- In a uniformly-expanding medium, each unit of distance expands at the same rate, thus the recessional velocity between points is directly proportional to distance; doubling the distance between points corresponds to doubling their relative velocity.
- Light travels at a finite speed; galaxies observed at greater distance (higher z) are observed at greater *lookback time*, or farther back on the modeled cosmic timeline from the current 'age of the Universe' back to the origin of that timeline at $\mathrm{T} = 0$.
- If we reverse the modeled expansion, then all of the galaxies occupy a volume of space that becomes smaller and smaller over time, culminating in a *hot and dense* 'singularity' of space and time that Sir Fred Hoyle flippantly dubbed the "Big Bang".

details
next 3
pages

Gyr : 1 billion (10^9) years

Gly : 1 billion (10^9) light years ~ 10^{22} km …

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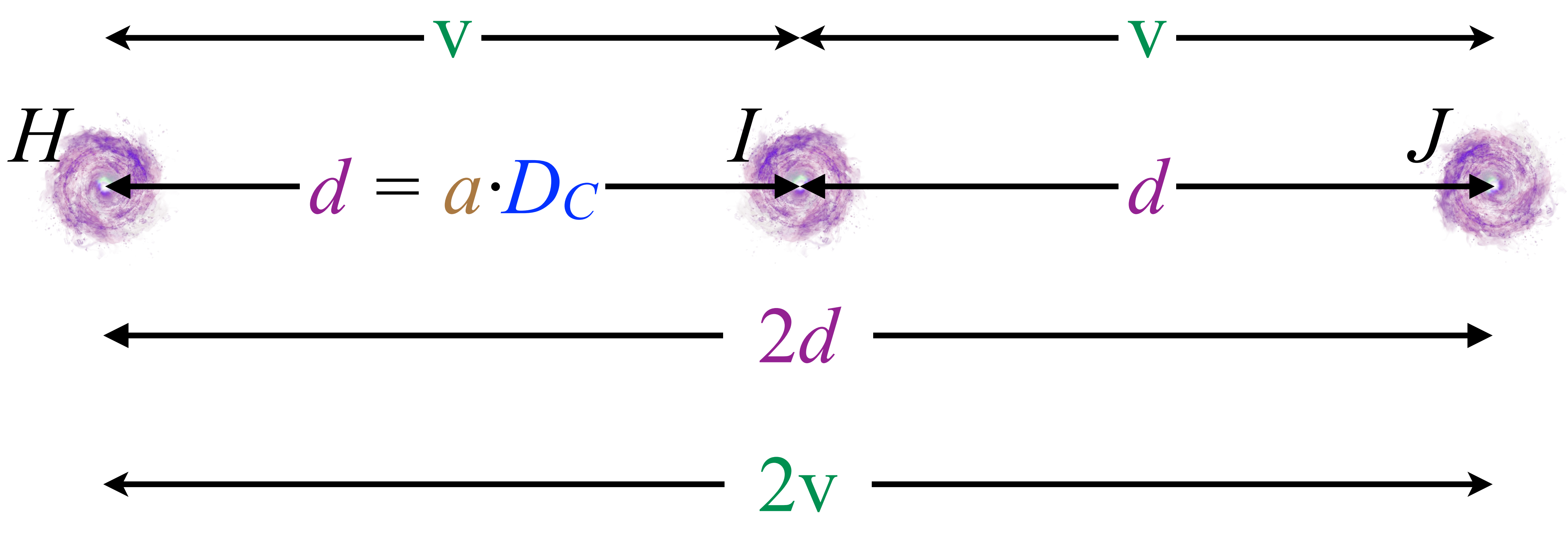
The canonical uniform cosmic expansion (A)

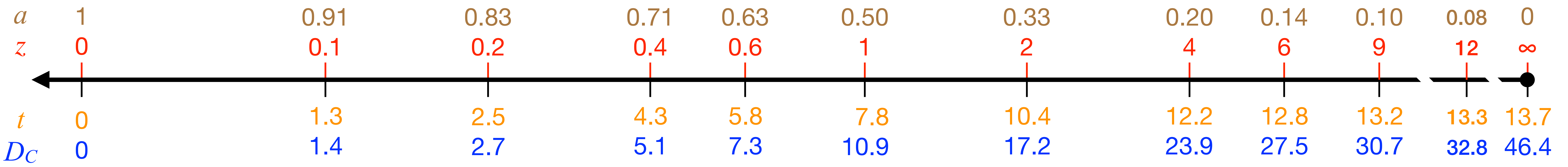


$D_C \leftrightarrow v$, $2D_C \leftrightarrow 2v$, $3D_C \leftrightarrow 3v$, etc.

- H and J are equidistant from I, and the distance H–J is $2d$.
- H and I mutually recede at speed v.
- J and I mutually recede at speed v.
- H and J mutually recede at speed $2v$.

The scale factor (a) is the cosmic radius (i.e., the 'size of the Universe') relative to now (1). The light travel time (t) is the difference between the cosmic age now and age at z. The comoving distance $D_C(z)$ to a particular object has a fixed value over time, similar to the angle between two points on the surface of an inflating ball. The proper distance in a particular epoch is $d = a \cdot D_C$, so d and D_C are equivalent now, and the proper distance between galaxies at $z > 12$ was considerably less than 1/10th of current values. The Hubble constant (H_0) is the current-epoch ($a = 1$) rate of expansion, typically measured in km/s/Mpc.

redshift (z) & scale factor $(1 + z)^{-1}$



a	1	0.91	0.83	0.71	0.63	0.50	0.33	0.20	0.14	0.10	0.08	0
z	0	0.1	0.2	0.4	0.6	1	2	4	6	9	12	∞
t	0	1.3	2.5	4.3	5.8	7.8	10.4	12.2	12.8	13.2	13.3	13.7
D_C	0	1.4	2.7	5.1	7.3	10.9	17.2	23.9	27.5	30.7	32.8	46.4

Observer

light travel time (Gyr) & comoving distance (Gly)

Big Bang

$H_0 = 69.6\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}}$
$\Omega_M = 0.286$ (mass fraction)
$\Omega_\Lambda = 0.714$ (cosmological constant)

Source of the canonical numerical values: https://astro.ucla.edu/~wright/CosmoCalc.html

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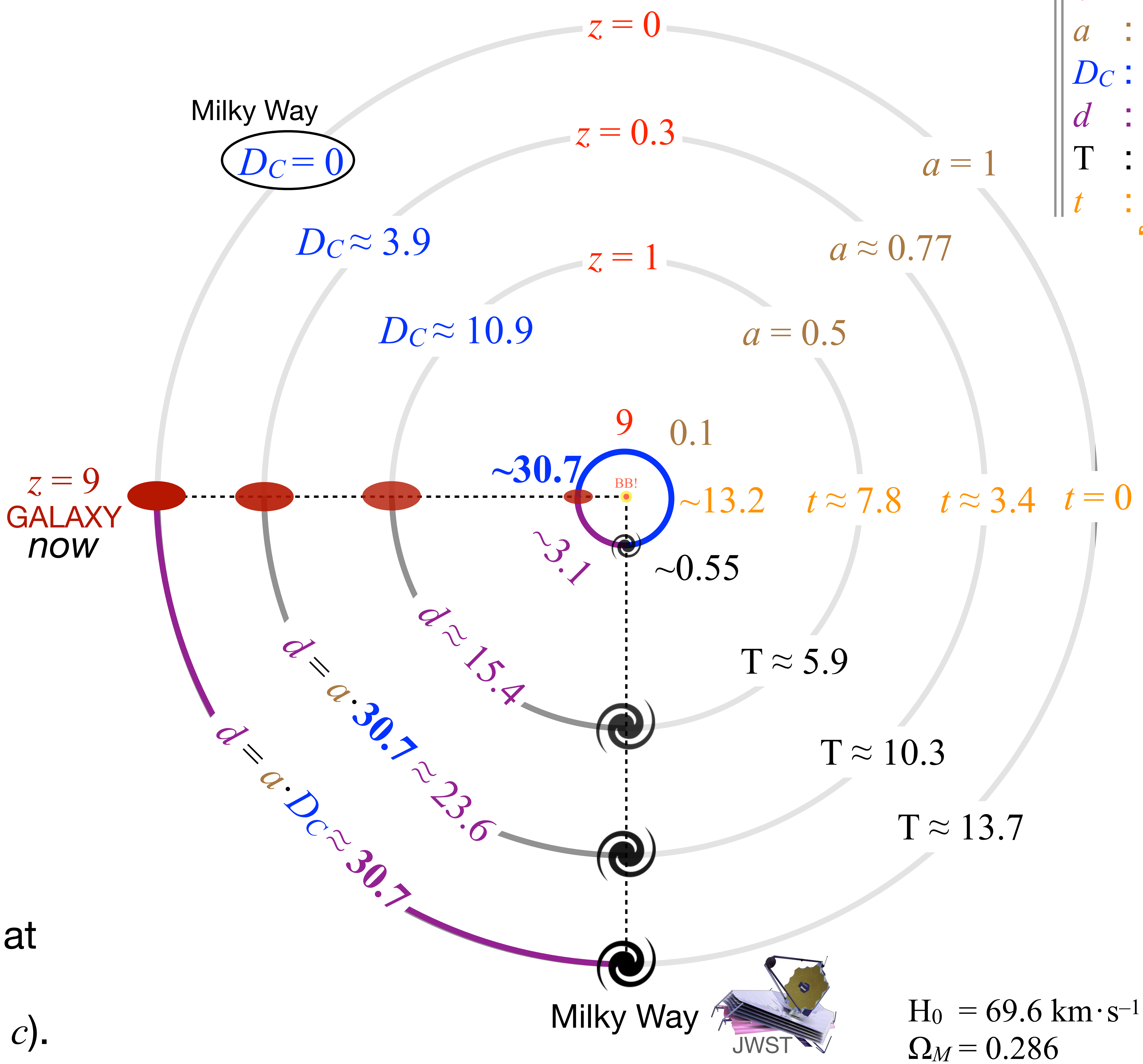
The canonical uniform cosmic expansion (B)

1. JWST observes a GALAXY ● at $z = 9$; it has *fixed coordinate* $D_C \approx \mathbf{30.7}$ Gly.
2. We observe that GALAXY ● as it existed $t \approx 13.2$ Gyr years ago (i.e., in *our* distant past).
3. At that time, the age of the Universe (i.e., the time since the Big Bang) was about 550 Myr ($T \approx 0.55$ Gyr).
4. At that time, the Universe was 1/10th ($a = 0.1$) its current size.
5. At that time, its distance from the Milky Way was $d = a \cdot D_C \approx 3.1$ Gly.
6. Due to cosmic expansion, its light ‘chased’ the receding Milky Way…
7. and it took $t \approx 13.2$ Gyr for that light to arrive at the JWST telescope.
8. At the current age of the cosmos ($T \approx 13.7$ Gyr), that GALAXY ● is *now* at a distance of $d = a \cdot D_C \approx \mathbf{30.7}$ Gly and receding at superluminal velocity ($v > c$).



z : redshift
a : scale factor
D_C : comoving distance (Gly)
d : proper distance (Gly)
T : cosmic age (Gyr)
t : light travel time (Gyr) “lookback”

BB! Inflationary epoch
$10^{-36} \lesssim T \lesssim 10^{-32}$ sec
$\Delta a \sim 10^{26}$

$H_0 = 69.6\ \text{km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$
$\Omega_M = 0.286$
$\Omega_\Lambda = 0.714$

Source of the canonical numerical values: https://astro.ucla.edu/~wright/CosmoCalc.html

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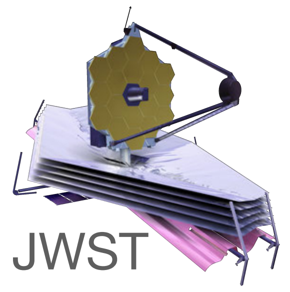
The canonical cosmic timeline

- From 2014–2022, the “1% Concordance” model ($H_0 = 69.6 \pm 0.7$, $\Omega_M = 0.286$, $\Omega_\Lambda = 0.714$) gave the much-publicized, and ostensibly well-established ‘age of the Universe’ to be about 13.7 billion years, the value that most people today were either taught in school, read about in a magazine, or saw in a television program or Internet science video.
- According to the latest (2022) claimed “precise measurement” of the Hubble constant ($H_0 = 73.30 \pm 1.04$) and “a consensus ΛCDM with $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$”, the modeled age of the Universe since the singularity has been revised, being reduced to ~12.9 Gyr.
- The ΛCDM model with the foregoing parameters correlates the measured redshift of a galaxy (z) with the modeled age of the Universe (T) at that redshift:



JWST is observing galaxies at $z > 12$…

redshift (z) & scale factor $(1 + z)^{-1}$

a	1	0.91	0.83	0.71	0.63	0.50	0.33	0.20	0.14	0.10	0.08	0
z	0	0.1	0.2	0.4	0.6	1	2	4	6	9	12	∞
T	**13.72**	12.41	11.27	9.40	7.94	5.90	3.32	1.56	0.94	0.55	0.37	0
	12.86	11.61	10.53	8.77	7.40	5.49	3.08	1.45	0.87	0.51	0.35	0

Present Canonical age of the Universe (Gyr) [1% Concordance model] ***Big Bang***

$H_0 = 73.30$
$\Omega_M = 0.3$
$\Omega_\Lambda = 0.7$

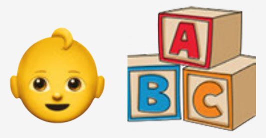
$H_0 = 69.6$
$\Omega_M = 0.286$
$\Omega_\Lambda = 0.714$

Source of the canonical numerical values: https://astro.ucla.edu/~wright/CosmoCalc.html

“Surveys with James Webb Space Telescope (JWST) have discovered candidate galaxies in the first 400 Myr of cosmic time. … Here we report on four galaxies located in the JWST Advanced Deep Extragalactic Survey (JADES) Near-Infrared Camera (NIRCam) imaging with photometric redshifts $z \sim 10 - 13$ subsequently confirmed by JADES JWST Near-Infrared Spectrograph (NIRSpec) observations. These galaxies include the first redshift $z > 12$ systems both discovered and spectroscopically confirmed by JWST.”

B. E. Robertson, S. Tacchella, B. D. Johnson, K. Hainline, L. Whitler et al., “Discovery and properties of the earliest galaxies with confirmed distances”, arXiv:2212.04480 [astro-ph.GA] (8 Dec 2022).

“These galaxies include the first redshift $z > 12$ systems” means galactic systems that are so populous and bright (i.e., *mature*) that they are readily observed at the farthest reaches of the observable Universe. Those cannot be labeled “baby galaxies” any more than an experienced commercial airline captain flying your jet can be confused with a toddler playing with blocks in a nursery school. Accordingly, the JWST empirical observations suggest that the foregoing consensus model (pp. 4–7) is *completely wrong*.



First data release
12 July 2022

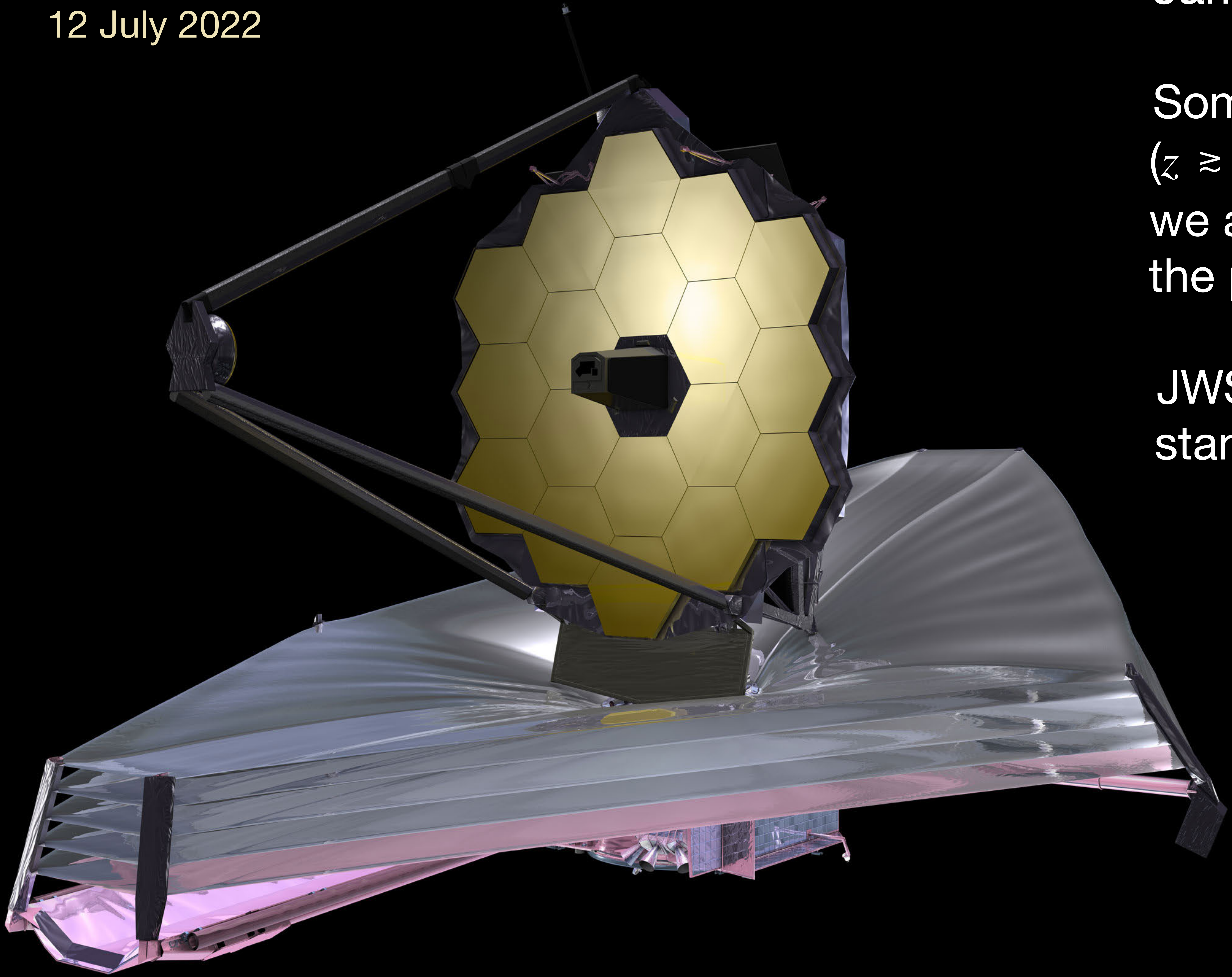


Image credit: NASA (Artist Impression)

James Webb Space Telescope (JWST)

Something is amiss; the distant Universe ($z \gtrsim 10$) obviously contains *old* galaxies; we are not just seeing ‘infant galaxies’ at the purported ‘beginning of time’.

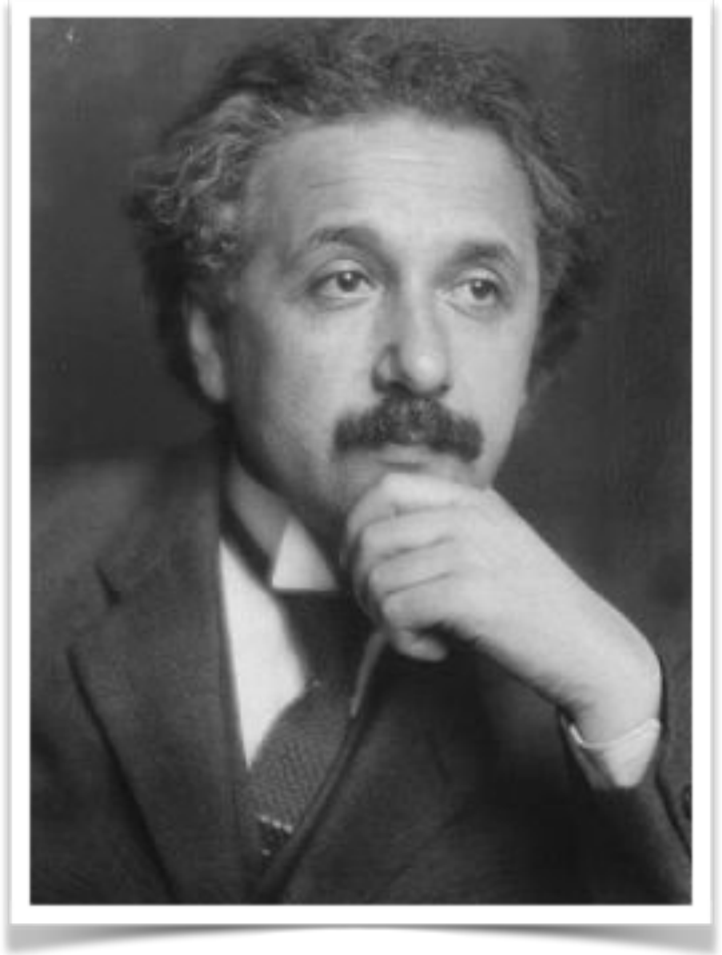
JWST data clearly overthrows the ΛCDM standard model of Big Bang cosmology.

Follow the data.

Throughout this presentation:
Focal points appear in magenta.
Internet links appear in light blue.

We will compare the *predictive accuracy* of two competing cosmological models.

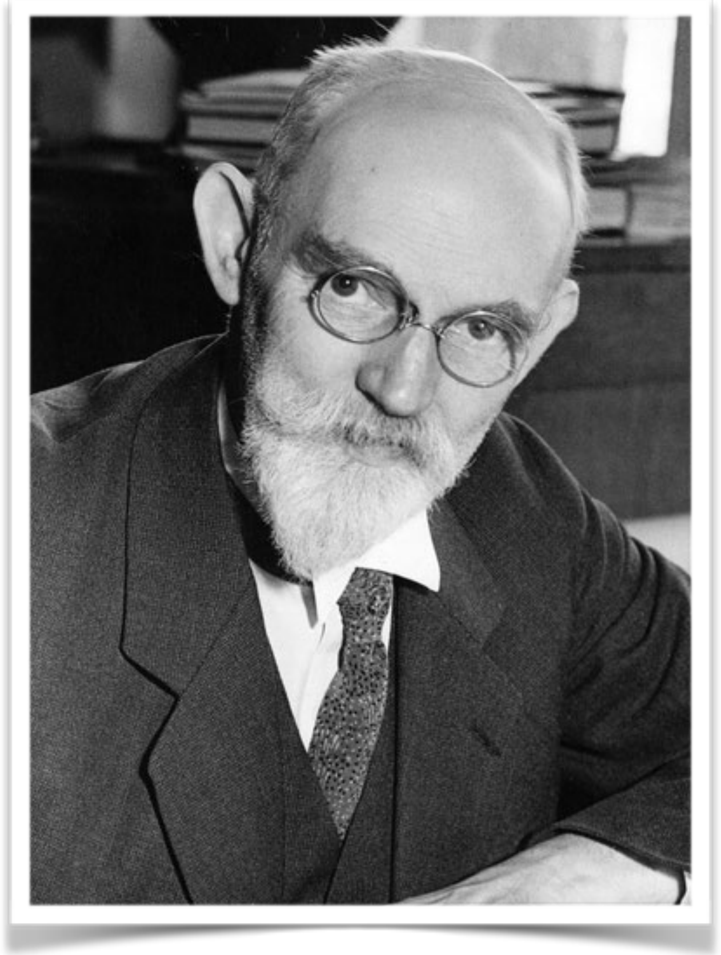
General Audience: IGNORE the unintelligible equations—they don't matter to you.
They are like a foreign language (外語), and it is perfectly OK that *you* don't know it.



Each model† is based on a distinct, known exact solution of the Einstein field equations.

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

Model A: Einstein (1917) → ΛCDM model



Model B: de Sitter (1917) → 'RTG'* model

* *Relativistic Temporal Geometry*, motivated by Minkowski (1909)

Pages 12–16 *preview* that comparison.

† The three new 'RTG' predictive formulas are a *logically consistent set* (i.e., any one formula can be true *if and only if* all three formulas are true).

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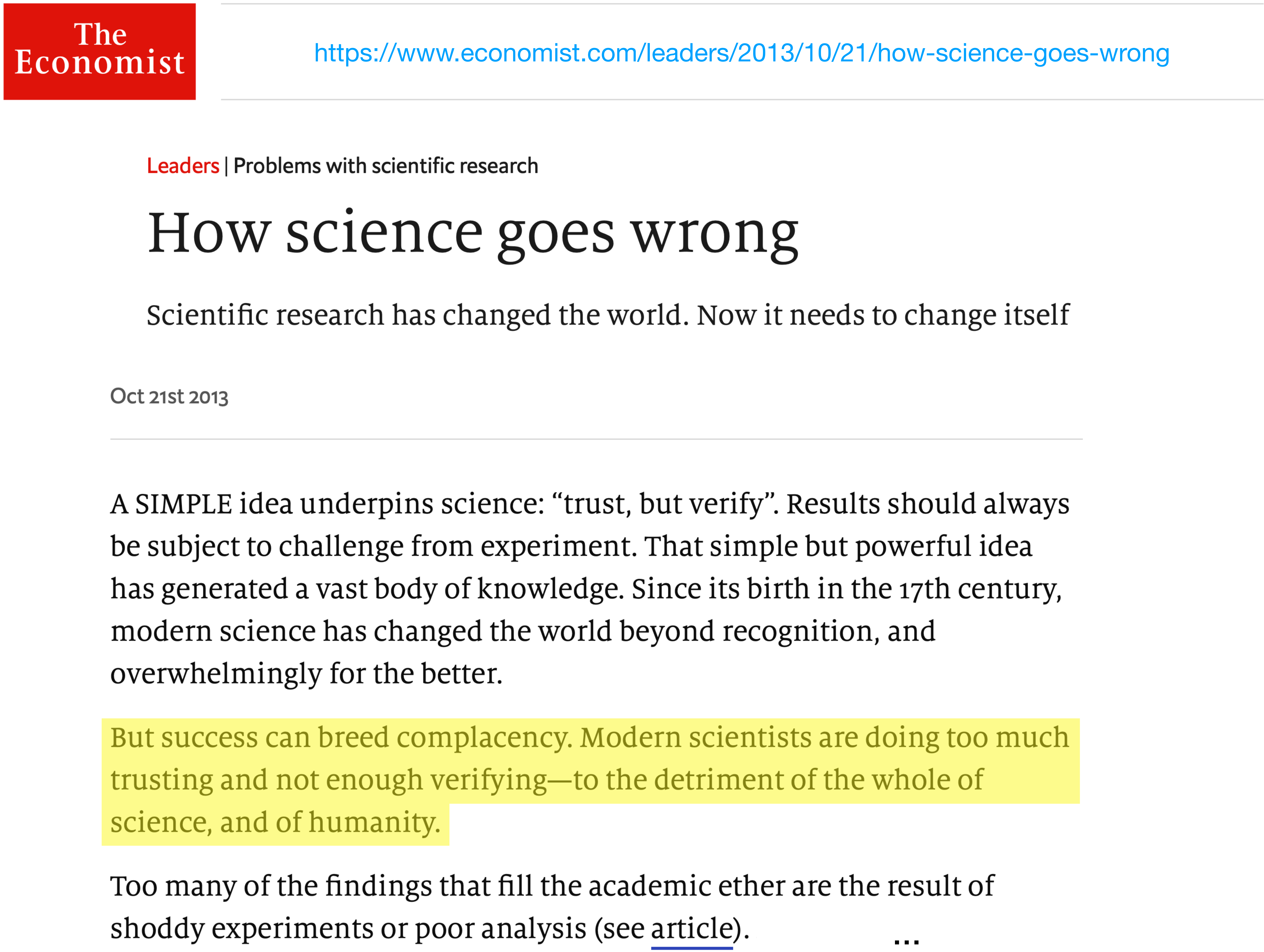


The Economist

https://www.economist.com/leaders/2013/10/21/how-science-goes-wrong

Leaders | Problems with scientific research

How science goes wrong

Scientific research has changed the world. Now it needs to change itself

Oct 21st 2013

A SIMPLE idea underpins science: “trust, but verify”. Results should always be subject to challenge from experiment. That simple but powerful idea has generated a vast body of knowledge. Since its birth in the 17th century, modern science has changed the world beyond recognition, and overwhelmingly for the better.

But success can breed complacency. Modern scientists are doing too much trusting and not enough verifying—to the detriment of the whole of science, and of humanity.

Too many of the findings that fill the academic ether are the result of shoddy experiments or poor analysis (see article). …

petroR50_$\overline{\text{gri}}$

[~2.4M measurements]

The data does not support the model (i.e., catastrophic* failure of the model)...

**irreconcilable*

As per differences in 'measurements' of (H_0, Ω_M, Ω_Λ), such variation has no appreciable effect on these curves.

RTG predictive model

$$\theta(z) = C_\ell \left(1 - \frac{1}{(z+1)^2}\right)^{-\frac{1}{2}} \quad , \quad C_\ell = 1$$

(Why not an arbitrary number?!)

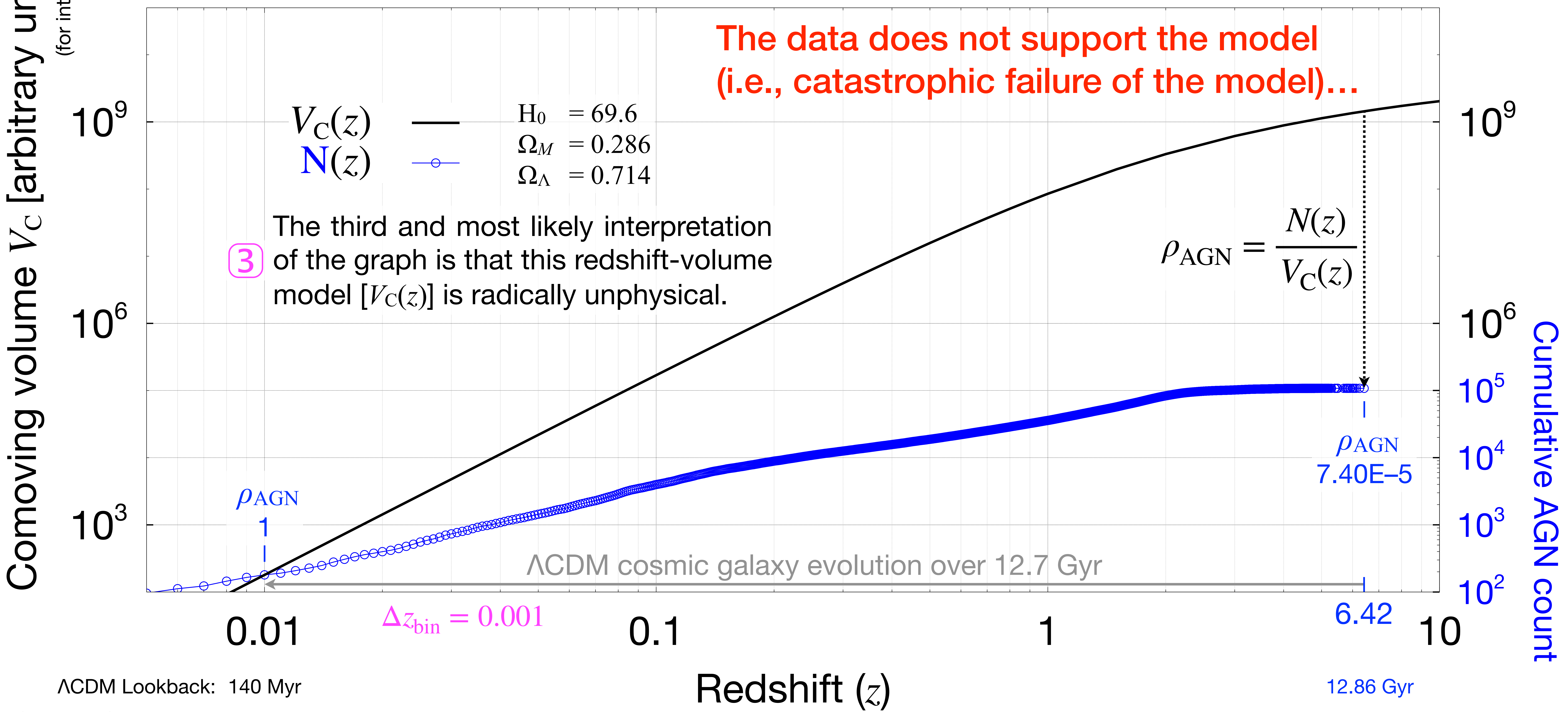
`petroR50_gri` with a bar over `gri`

There are *no free parameters* to modify the curve;
C_ℓ merely shifts the curve up or down on the θ-axis.

amayer@alum.mit.edu • SensibleUniverse.net • Data: SDSS

① ΛCDM: over time, AGN space density increases by ~4 orders of magnitude.

② Another possible interpretation of the graph, is that ≪1% of AGN that exist at higher redshift are observed and counted by the various astronomical surveys.



The data does not support the model (i.e., catastrophic failure of the model)…

③ The third and most likely interpretation of the graph is that this redshift-volume model [$V_C(z)$] is radically unphysical.

$$\rho_{\text{AGN}} = \frac{N(z)}{V_C(z)}$$

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S^3 represents the volumetric ‘surface’ of a Riemannian 3-sphere

The fit of this a priori theoretical predictive curve to the empirical AGN population data is equally remarkable to that for the theta-z data; there are no free parameters available to achieve this fit.

The interpretation of this graph is that AGN are accurately counted, even out to very high redshift, and that galaxy clusters comprise a fixed percentage of AGN throughout the Universe.

RTG predictive model

$$S^3(z) = C_V \cdot \left[\cos^{-1}\left(\frac{1}{z+1}\right) - \left(\frac{1}{(z+1)^2} - \frac{1}{(z+1)^4}\right)^{\frac{1}{2}}\right]$$

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RTG:

$$m(z) = C_M - 2.5\log\left[\frac{1}{4\pi\left((z+1)^4-(z+1)^2\right)}\right] + \epsilon_\lambda \cdot \cos^{-1}\left(\frac{1}{z+1}\right)$$

$C_M = 14.82,\ 13.22 \quad \epsilon_\lambda = 0.5$

$C_M = 15.17,\ 13.57 \quad \epsilon_\lambda = 0$

ΛCDM:

$$m(z) = K_M - 2.5\log\left[\frac{1}{4\pi D_L^2}\right]$$

$K_M = -0.68,\ -2.28$

Data: ~136k
SDSS LRGs (z-band)

The data does not support this model.

The SDSS Luminous Red Galaxies (LRGs) were specifically selected to have similar characteristics, including their luminosity.

Redshift-magnitude curves modeling constant intrinsic brightness

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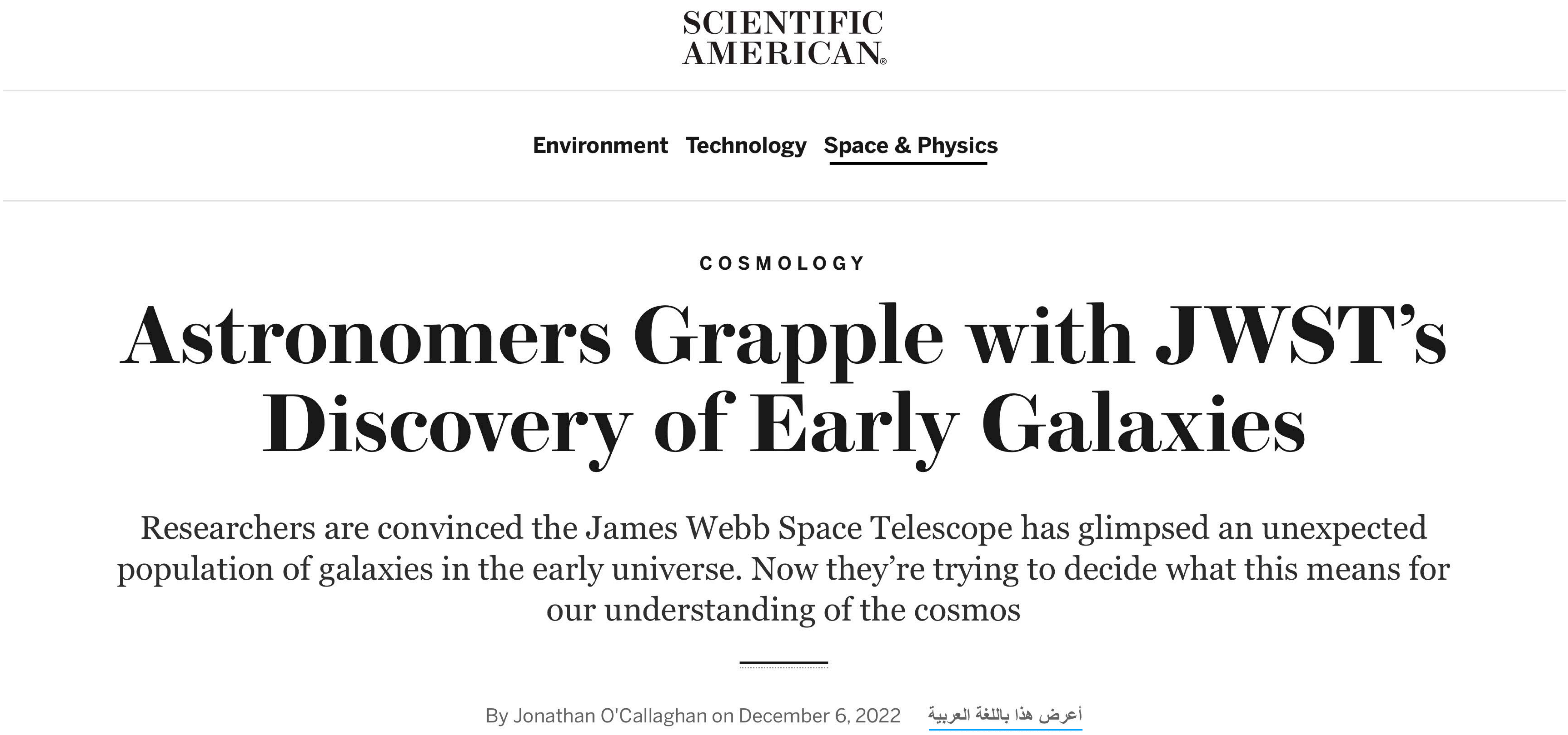
Note: g-band data must exhibit 4000 Å break!

End *Preview — Main Discourse*



COSMOLOGY

Astronomers Grapple with JWST’s Discovery of Early Galaxies

Researchers are convinced the James Webb Space Telescope has glimpsed an unexpected population of galaxies in the early universe. Now they’re trying to decide what this means for our understanding of the cosmos

By Jonathan O'Callaghan on December 6, 2022 أعرض هذا باللغة العربية

https://www.scientificamerican.com/article/astronomers-grapple-with-jwsts-discovery-of-early-galaxies1/

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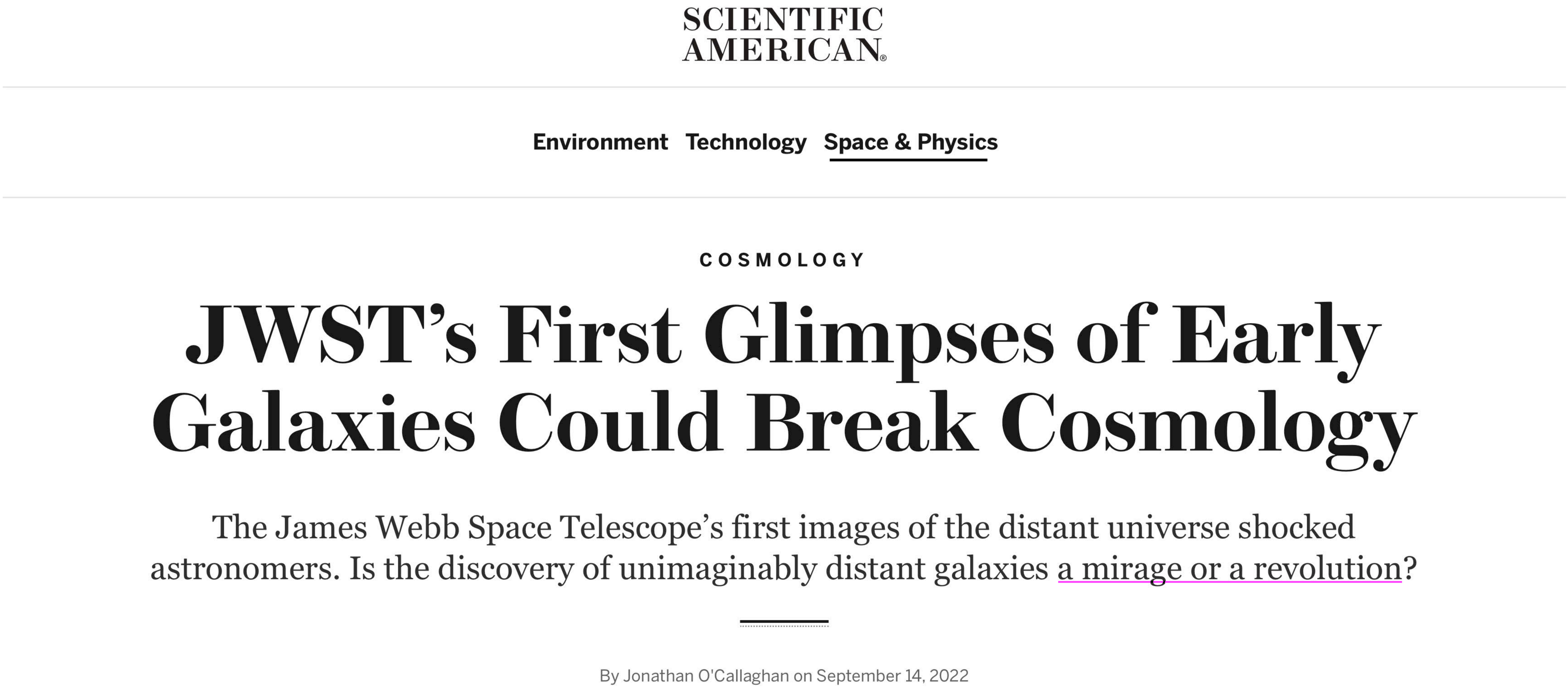
ASTRONOMY

How JWST Is Changing Our View of the Universe

The James Webb Space Telescope has sparked a new era in astronomy

By Clara Moskowitz on December 1, 2022

https://www.scientificamerican.com/article/how-jwst-is-changing-our-view-of-the-universe/



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COSMOLOGY

JWST's First Glimpses of Early Galaxies Could Break Cosmology

The James Webb Space Telescope's first images of the distant universe shocked astronomers. Is the discovery of unimaginably distant galaxies a mirage or a revolution?

By Jonathan O'Callaghan on September 14, 2022

Not "a mirage", but indeed "a revolution"…

https://www.scientificamerican.com/article/jwsts-first-glimpses-of-early-galaxies-could-break-cosmology/

https://indico.cern.ch/event/1153372/contributions/5200955/

Speaker

ALEXANDER MAYER

Description

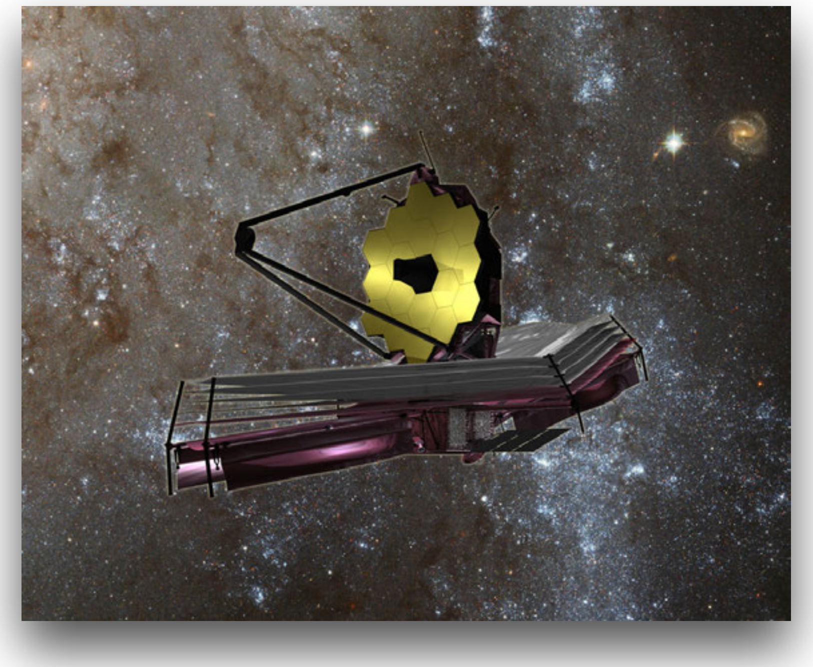
We present empirical evidence from the Sloan Digital Sky Survey (SDSS), including statistically-significant, independent measurements of galaxy theta-z, redshift-magnitude, and redshift-population. These corroborating data sets are clearly inconsistent with the optimal ΛCDM standard model of Big Bang cosmology, exacerbating the Hubble constant tension; the σ8 (clustering parameter) discrepancy; the lensing anomaly; the large-angular-scale anomalies in CMB temperature and polarization; and other anomalies that now confront cosmologists. A set of predictive equations are put forward that are consistent with de Sitter's exact solution to the Einstein field equations. This new "temporal geometry" predictive model, which requires vetting by the mathematical physics and cosmology communities, is consistent with the high-quality SDSS data and relieves the unexpected new tensions in cosmology created by the initial and ongoing James Webb Space Telescope (JWST) observations.

Primary author

ALEXANDER MAYER

Patagonia
Jan 2020

"It will be interesting to see where ignoring me will take you in the long term."
– Steven Magee



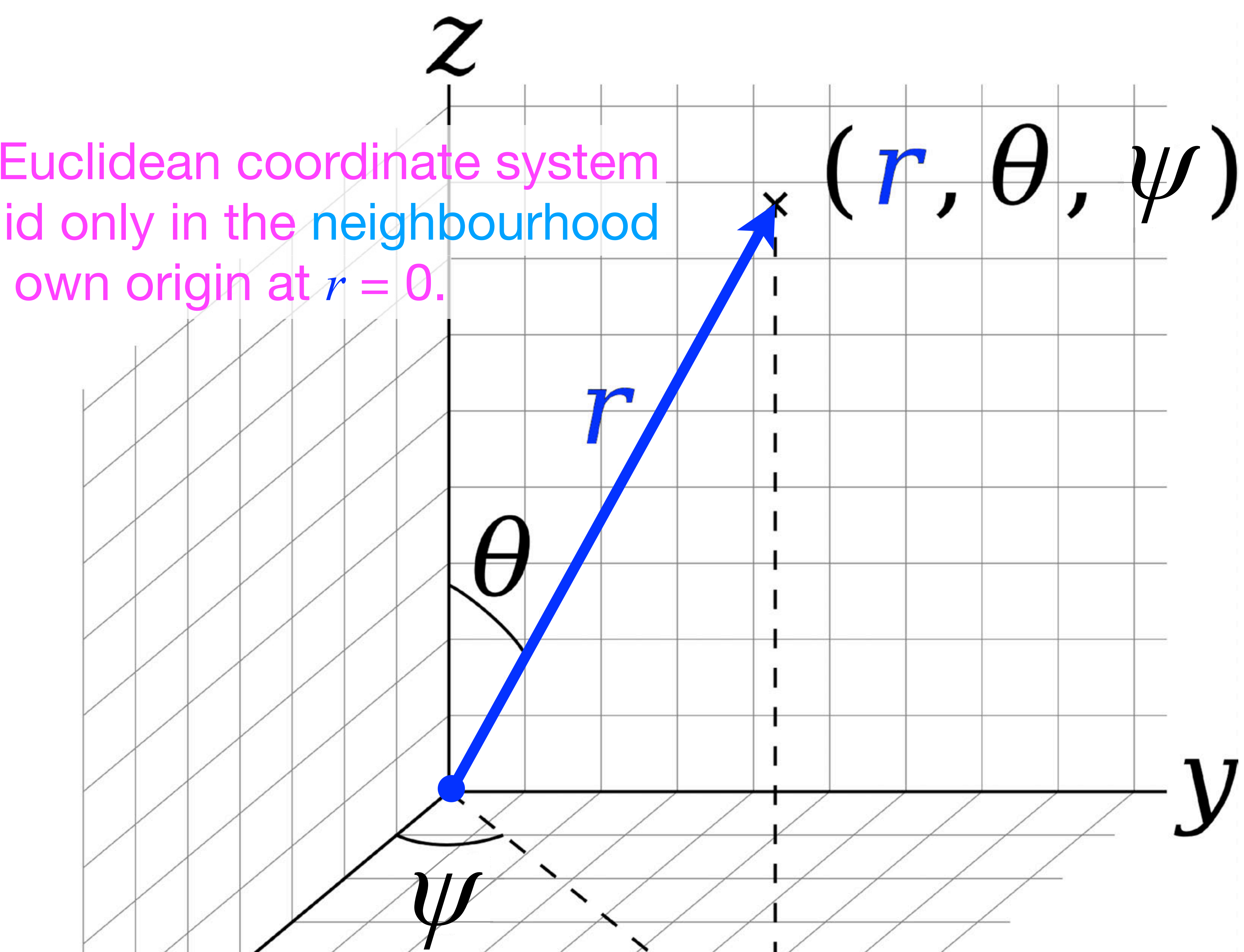
"When I was starting out in mathematics, it seemed very important to prove a big theorem. Now, with more experience, I understand that it is *new notions* that are more important, for example, Alan Turing's new notion of computability, which I shall discuss today."

– **Yuri Ivanovich Manin**, ***Talk on Computability***, **Northwestern University (c. 1995)**

I thank Dr. Michael Stephen Fiske, Ph.D. Mathematics, Northwestern (1996) for this quotation.

Spherical coordinate system (r, θ, ψ)

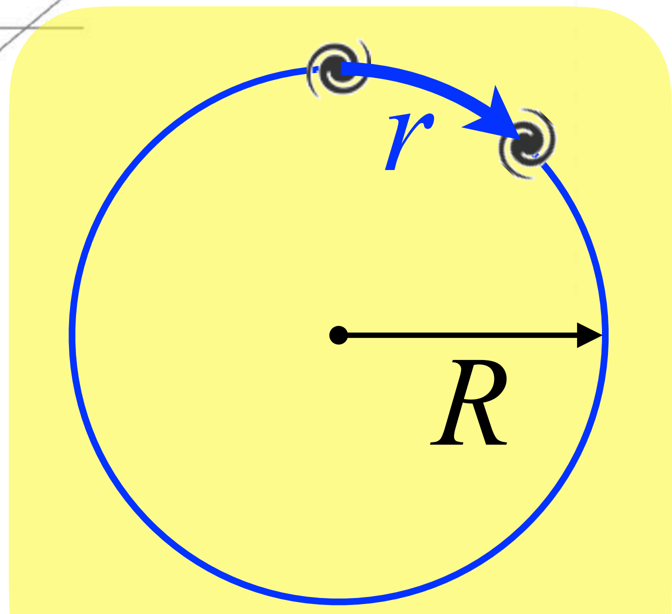
This Euclidean coordinate system is valid only in the neighbourhood of its own origin at $r = 0$.



$$ds^2 = x^2 + y^2 + z^2 + (ict)^2$$

local Minkowski metric

Note that $i^2 = -1$



page-23 preview

The following page (23) presents Einstein's 1917 exact solution of the field equations in the form of a metric (i.e., an equation that measures distance).

It is important to understand that the locally-defined blue vector r here is the *same dimension* of physical space as the blue arc r on page 23, and that the dot at the origin here can represent any point on the circle.

The interior region of the blue circle of radius R does not represent space; the other two space dimensions (θ, ψ), over which distances between galaxies can be measured, are not represented in the diagram.

We call the Euclidean coordinate system on the left, which represents *strictly-locally-defined* measurable 3-dimensional physical space, a tangent space.

Each such tangent space has a 4th coordinate, t that represents time as locally measured in that space; t is mutually orthogonal to the three space coordinates in accord with the *locally*-applicable Minkowski metric.

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Model A

Einstein's metric —an exact solution of the Einstein field equations (EFE)

$$ds^2 = -\,dr^2 - R^2 \sin^2\left(\frac{r}{R}\right)\left[d\psi^2 + \sin^2(\psi)\,d\theta^2\right] \boxed{+\,c^2 dt^2}$$

1) The Universe is finite, yet has no boundary. ✓

2) Time is *independent* of space in the metric.

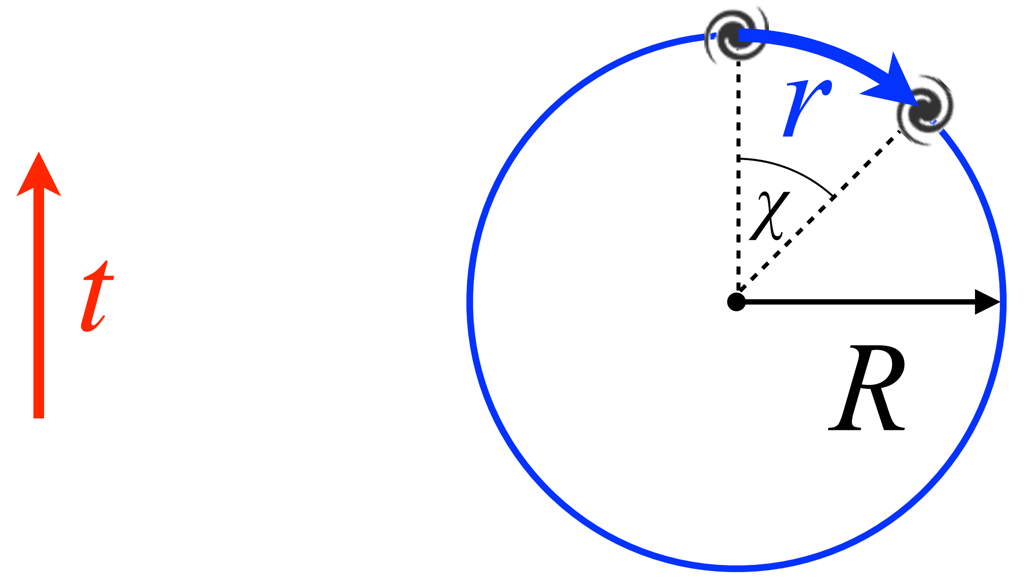
The blue circle represents a cosmological great circle — a *single* dimension of measurable physical space in two dimensions of $\mathbb{R}^4$.

$\mathbb{R}^4$ means a 4D Euclidean space, which may contain a 4-dimensional sphere.

$$d\theta = d\Psi = 0$$

$$d\chi \equiv \frac{dr}{R}$$

$$D_C \propto \chi$$



Riemannian geometry ✓
vs.
Euclidean geometry

$R \propto a$ (dimensionless cosmic scale factor)

A. Einstein, "Cosmological Considerations in the General Theory of Relativity", *SPAW*, 142 (1917).

Referencing Einstein’s metric, expressed using $x_4 \equiv t$

“We thus find that in the System *A* the time has a separate position. That this must be so, is evident a priori. For speaking of *the* three-dimensional world, if not equivalent to introducing an absolute time, at least implies the hypothesis that at each point of the four-dimensional space there is one absolute coordinate x_4 which is preferable to all others to be used as “time”, and that at all points and always this one coordinate is actually chosen as time. Such a fundamental difference between the time and the space-coordinates seems to be somewhat contradictory to the complete symmetry of the field-equations…”

– Willem de Sitter (31 March 1917)

W. de Sitter, “On the relativity of inertia. Remarks concerning Einstein’s latest hypothesis”, *KNAW Proceedings* **19**(2), 1217 (1917).

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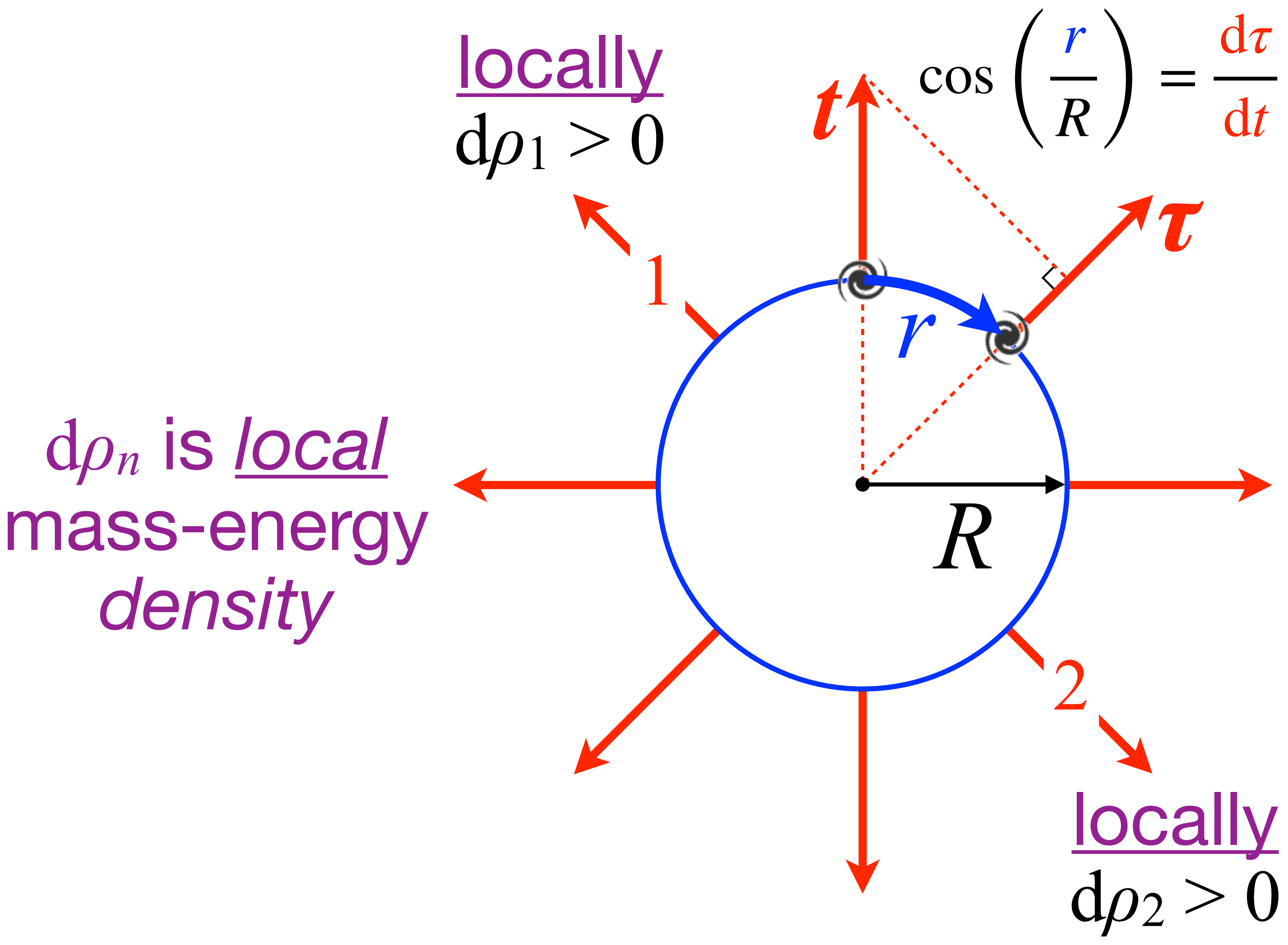
Model B

Willem de Sitter's metric — a different exact solution to the EFE

$$ds^2 = -\,dr^2 - R^2 \sin^2\left(\frac{r}{R}\right)\left[d\psi^2 + \sin^2(\psi)\,d\theta^2\right] + \overset{c^2 d\tau^2}{\boxed{\cos^2\left(\frac{r}{R}\right) c^2 dt^2}}$$

1) The Universe is finite, yet has no boundary.

2) Time is *dependent* on space in the metric.



locally
$d\rho_1 > 0$
t
$\cos\left(\frac{r}{R}\right) = \frac{d\tau}{dt}$
τ
1
r
$d\rho_n$ is *local* mass-energy *density*
R
2
locally
$d\rho_2 > 0$

This *interpretation* of de Sitter's metric, where time is a strictly-local *geometric object* is **new**. It also elegantly resolves the quandary of *zero* cosmic matter density imposed by this solution.

relativistic perspective → Universal perspective

energetic *relationship* $d\rho_2 = -\,d\rho_1 \quad \therefore \quad \int_0^{2\pi} d\rho = \rho = 0$ density

W. de Sitter,
"Einstein's theory of gravitation and its astronomical consequences. Third paper", *MNRAS* **78**, 3 (1917).

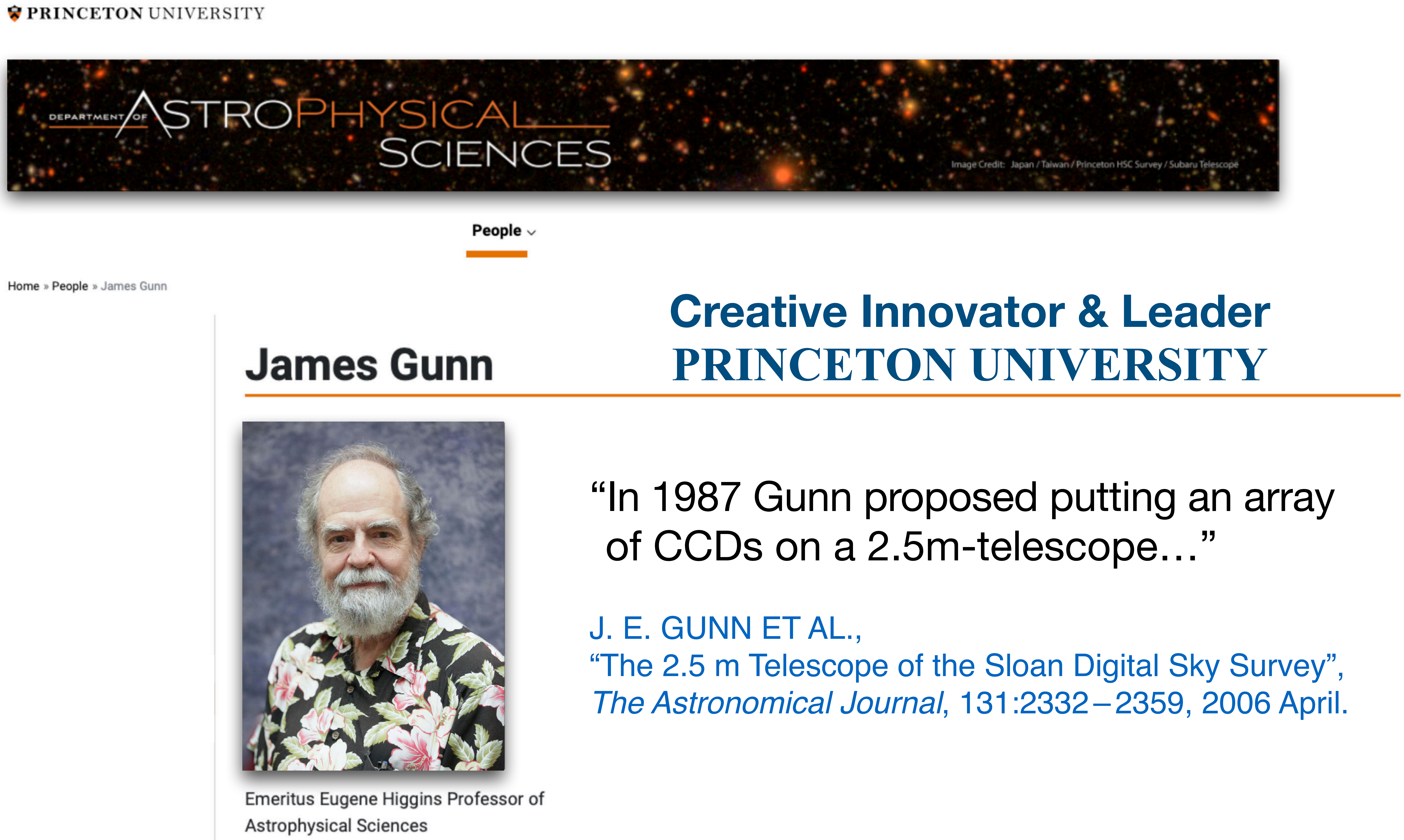


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Image Credit: Japan / Taiwan / Princeton HSC Survey / Subaru Telescope
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Creative Innovator & Leader
PRINCETON UNIVERSITY

James Gunn

Emeritus Eugene Higgins Professor of Astrophysical Sciences

"In 1987 Gunn proposed putting an array of CCDs on a 2.5m-telescope…"

J. E. GUNN ET AL.,
"The 2.5 m Telescope of the Sloan Digital Sky Survey",
The Astronomical Journal, 131:2332–2359, 2006 April.

Adapted from a screen shot of Gunn's official web page at Princeton.

Sloan Digital Sky Survey

SDSS.org

Sloan Foundation
2.5-m Telescope

photo credit: Reidar Hahn, *Fermilab Visual Media Services*

Apache Point Observatory
Sunspot, New Mexico, USA

🌱 ⚰️

Theories live and die by *__accurate__* empirical data.

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Theta-z log-log plot of half-light radius (`petroR50`) for **~800k galaxies**

Theta-z ≡ “*apparent* size versus redshift”

≡ means “equivalent to”

EACH DOT REPRESENTS ONE GALAXY

BLUE: sparser data → **RED**: denser data

Color scaling is logarithmic.

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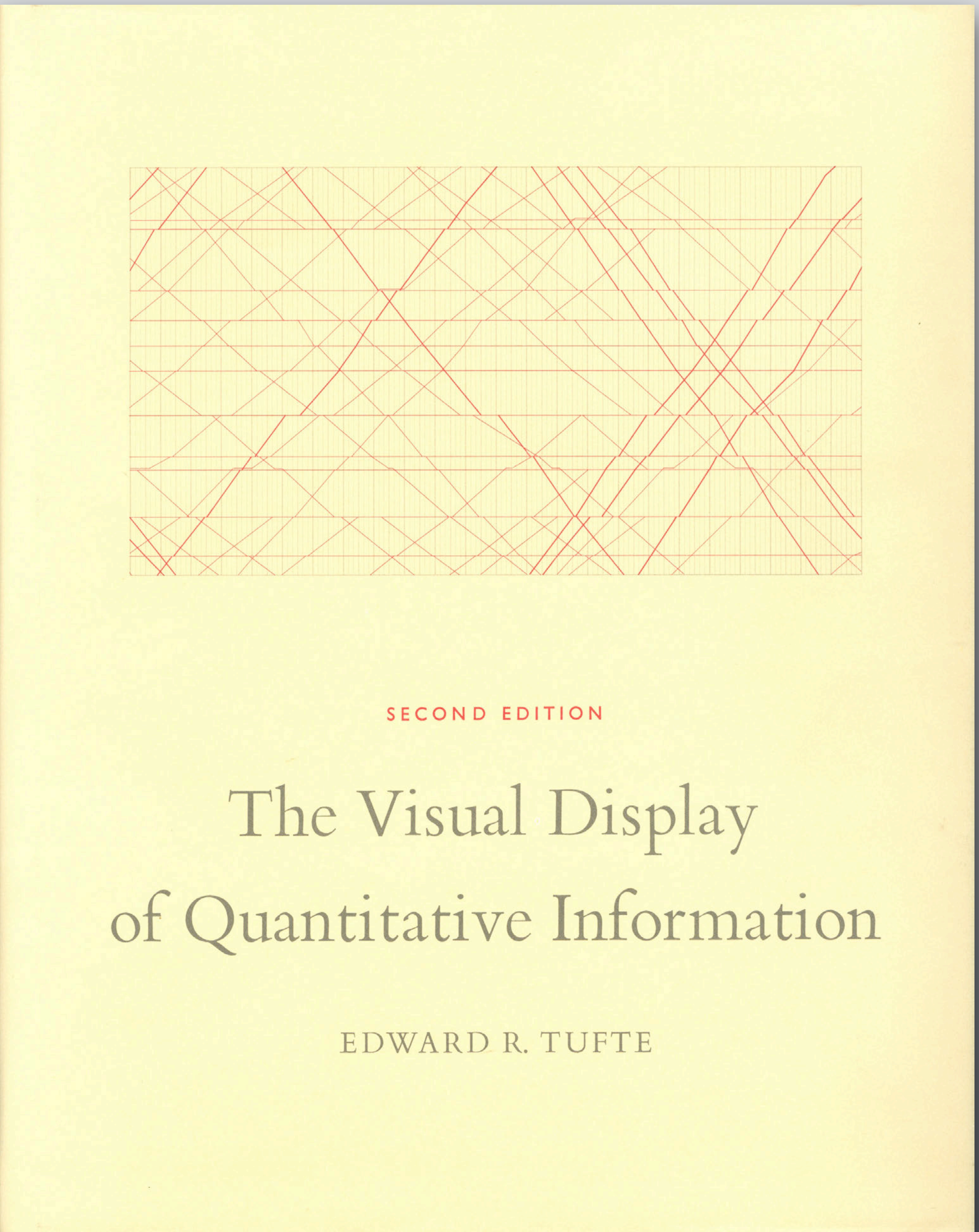
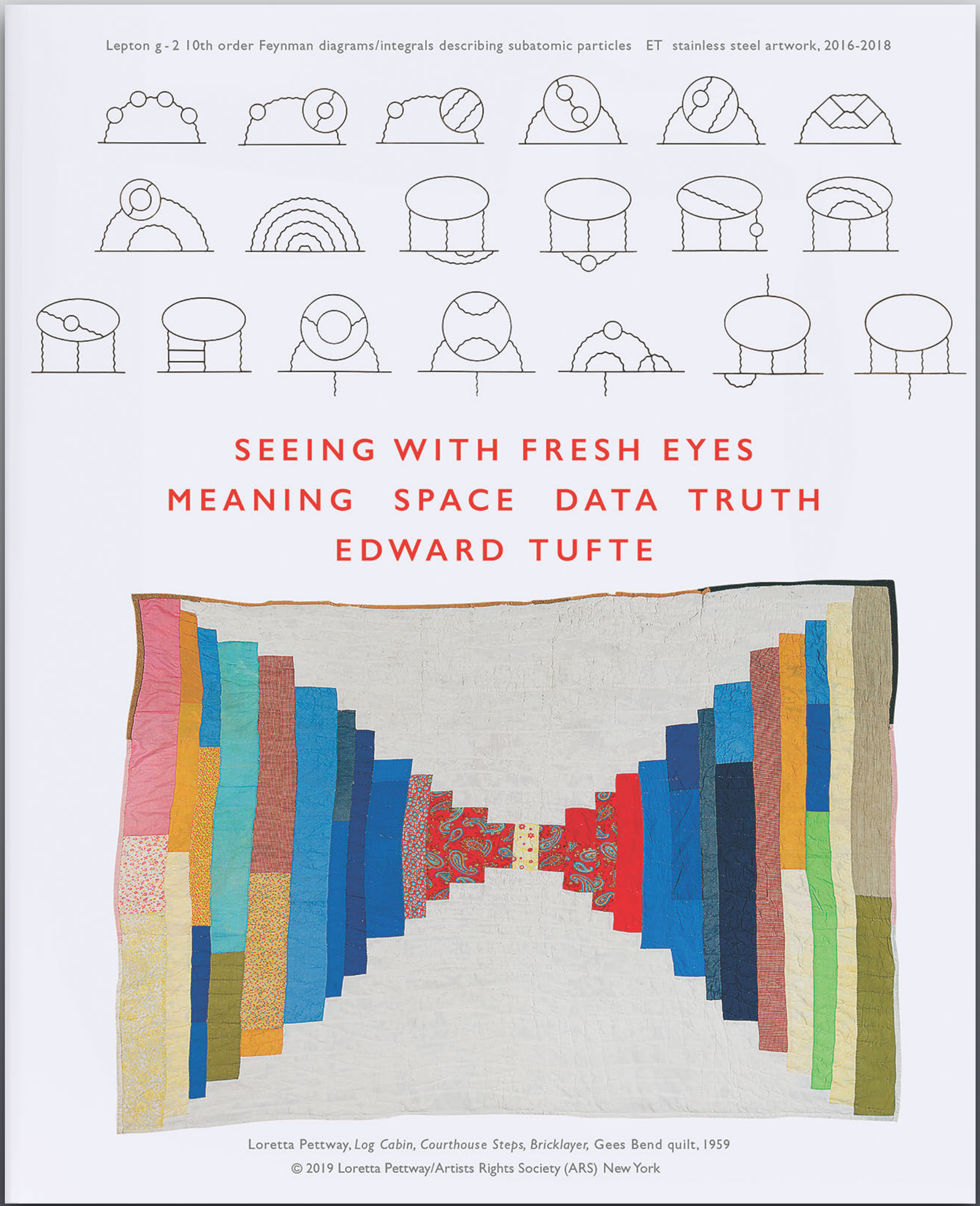


SECOND EDITION

The Visual Display of Quantitative Information

EDWARD R. TUFTE



Lepton g-2 10th order Feynman diagrams/integrals describing subatomic particles ET stainless steel artwork, 2016-2018

SEEING WITH FRESH EYES
MEANING SPACE DATA TRUTH
EDWARD TUFTE

Loretta Pettway, *Log Cabin, Courthouse Steps, Bricklayer,* Gees Bend quilt, 1959
© 2019 Loretta Pettway/Artists Rights Society (ARS) New York

edwardtufte.com

SDSS glossary reference

petroRad

The Petrosian radius. A measure of the angular size of an image, most meaningful for galaxies. Units are seconds of arc. The Petrosian radius (and related measures of size called `petroR50` and `petroR90`) are derived from the surface brightness profile of the galaxy, as described in Algorithms.

Surface Brightness

The frames pipeline also reports the radii containing 50% and 90% of the Petrosian flux for each band, `petroR50` and `petroR90` respectively.

Source: https://www.sdss.org/dr14/help/glossary/#P

Every galaxy plotted includes this basic empirical data and far more.

theta-*z* coordinates of this galaxy

ra	09:31:23.36
dec	05:16:09.77
equinox	J2000
scale	0.198 arcsec/pix
width	720 arcmin
height	720 arcmin

petroR50_g	9.70912
petroR50_r	9.775274
petroR50_i	9.83906
petroR50_gri	**9.77448**
z	**0.07624228**
zErr	2.464148E-05

petroRad_g	18.22892
petroRad_r	18.6974
petroRad_i	18.64179
petroRad_gri	**18.52270**

Click for more data...

SDSS 18
finding chart

ObjID: 1237658298990330048

Survey: sdss Program: *legacy* Target: *GALAXY_RED GALAXY*
RA=142.84737, Dec=5.26938, Plate=992, Fiber=184, MJD=52644
z=0.07624±0.00002 Class=GALAXY STARFORMING
No warnings.

SDSS astronomical band-pass filters λ_{eff} (Å)

Ultraviolet	Green	Red	Near Infrared	Infrared
u	**g**	**r**	**i**	**z**
3531	4627	6140	7467	8887

Not *redshift* (z)!

disambiguation for a general audience

Central wavelengths λ_{eff} (Å) from Doi et al. (2010), Table 2.

photo credit: *Smithsonian National Air and Space Museum*

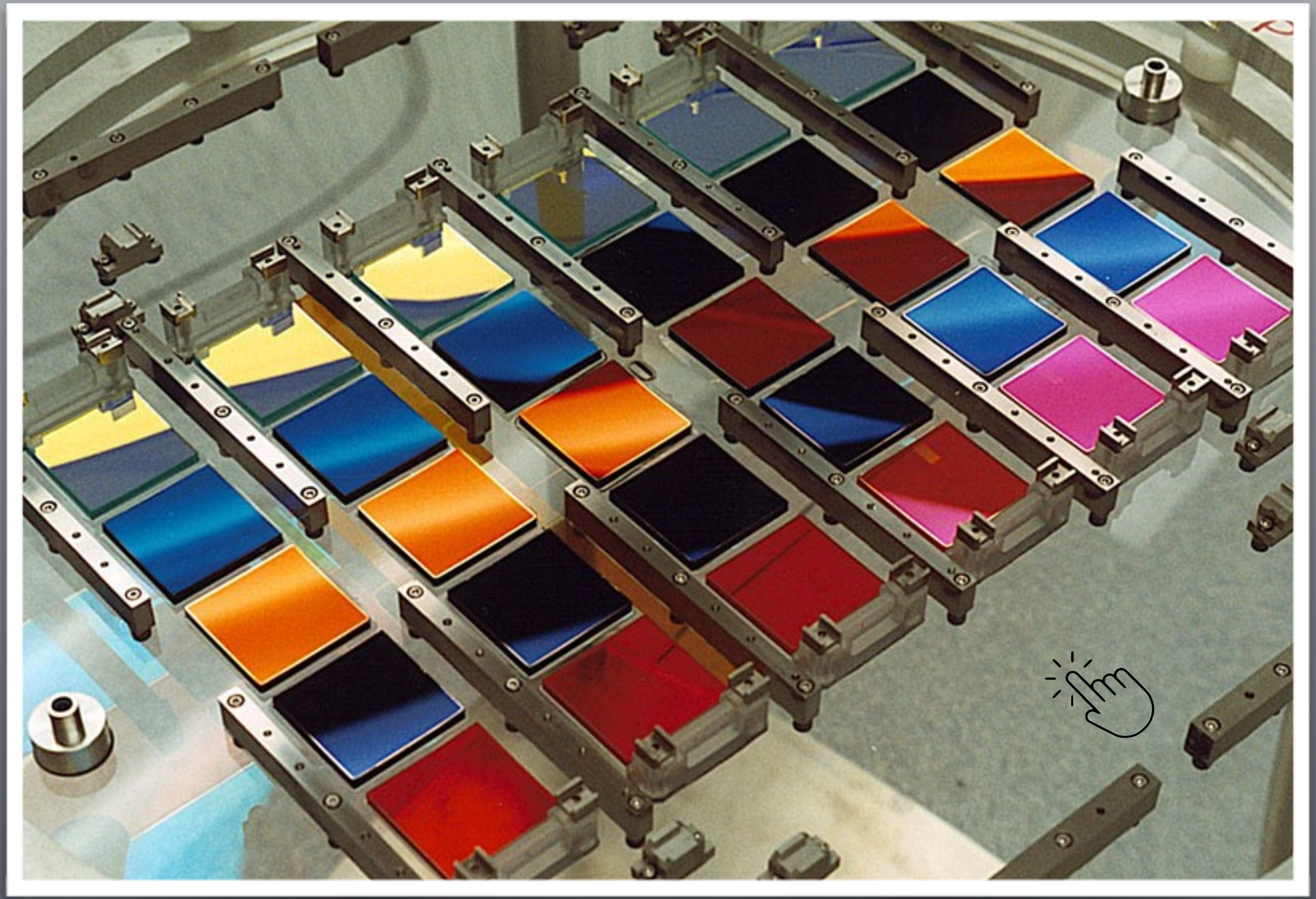


photo credit: *Michael Carr*

Click for article…

~2.4×10⁶ Empirical Measurements

Too many measurements to “massage” the data according to confirmation bias.

~2.4 MILLION measurements

There are 795,838 galaxies (dots) represented in this graph, and each dot represents the average of 3 distinct (**g**, **r**, **i**) radius measurements.

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petroR50_$\overline{\text{gri}}$

Far away, the faint outer regions of the largest galaxies are not seen, so they appear smaller.

Galaxies at the peak of each reference rod are 10× greater in measured radius than those at the base.

SDSS cannot see the smallest galaxies at this great distance.

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Empirical Inference

①

The *intrinsic* radial size of *typical* galaxies, including all morphologies, spans an order of magnitude (i.e., ×10), which decadal range excludes statistically-unlikely outliers.

Inference ǀ ˈinf(ə)rəns ǀ

noun

a conclusion reached on the basis of evidence and reasoning: *researchers are entrusted with drawing inferences from the data.*

7 Redshift ($\bar{z}$) Bins

Each bin allows us to examine a group of galaxies that are close to each other in *redshift* (i.e., at about the same distance).

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Measurement-error ellipses for $\bar{z}$ = 0.080 (5% regular sample of the bin)

nth selection sample interval = 20

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Measurement-error ellipses for $\bar{z}$ = 0.320 (5% regular sample of the bin)

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Radius measurement error (`petroR50Err`) as a percent of the measurement

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A Massive Volume of **High-Quality Data**

Principle galaxy selection criteria:

- Maximum allowed radius-measurement error in *any* of the three bands is 20%.
- Maximum allowed redshift error is 1%.

Plotted theta-z data set:

- Average $\overline{\mathbf{gri}}$ radius-measurement error is **3.6%**.
- Average redshift-measurement error is **0.021%**.

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Redshift Bin Statistics for `petroR50_`$\overline{\texttt{gri}}$ (Geometric vs. Arithmetic)

log-normal distribution ✓ normal distribution ✗

Minimum Redshift $z_{\min}$	Maximum Redshift $z_{\max}$	**Average Redshift** $\bar{z} = \sum z \div \mathrm{N}$	**Galaxy count** N	**StdDev[** $\ln(r)$ **]** σ	$\overline{\ln(r)}$ μ	**Mean Radius** $\bar{\theta} = e^{\left(\mu+\frac{\sigma^2}{2}\right)}$	**Median Radius** e^{μ}	**Standard Deviation** e^{σ}
0.0090	0.0110	**0.010**	398	0.6711	1.5170	**5.71**	4.56	1.96
0.0180	0.0220	**0.020**	3,483	0.5593	1.3984	**4.73**	4.05	1.75
0.0380	0.0420	**0.040**	8,345	0.4686	1.1179	**3.41**	3.06	1.60
0.0760	0.0840	**0.080**	38,831	0.3870	0.8200	**2.45**	2.27	1.47
0.1520	0.1680	**0.160**	34,762	0.2952	0.7156	**2.14**	2.05	1.34
0.3040	0.3360	**0.320**	36,487	0.2297	0.4503	**1.61**	1.57	1.26
0.6100	0.6780	**0.640**	7,147	0.2236	0.1637	**1.21**	1.18	1.25

Empirical Galaxy-Size Distribution

Not much useful data here at low-redshift…

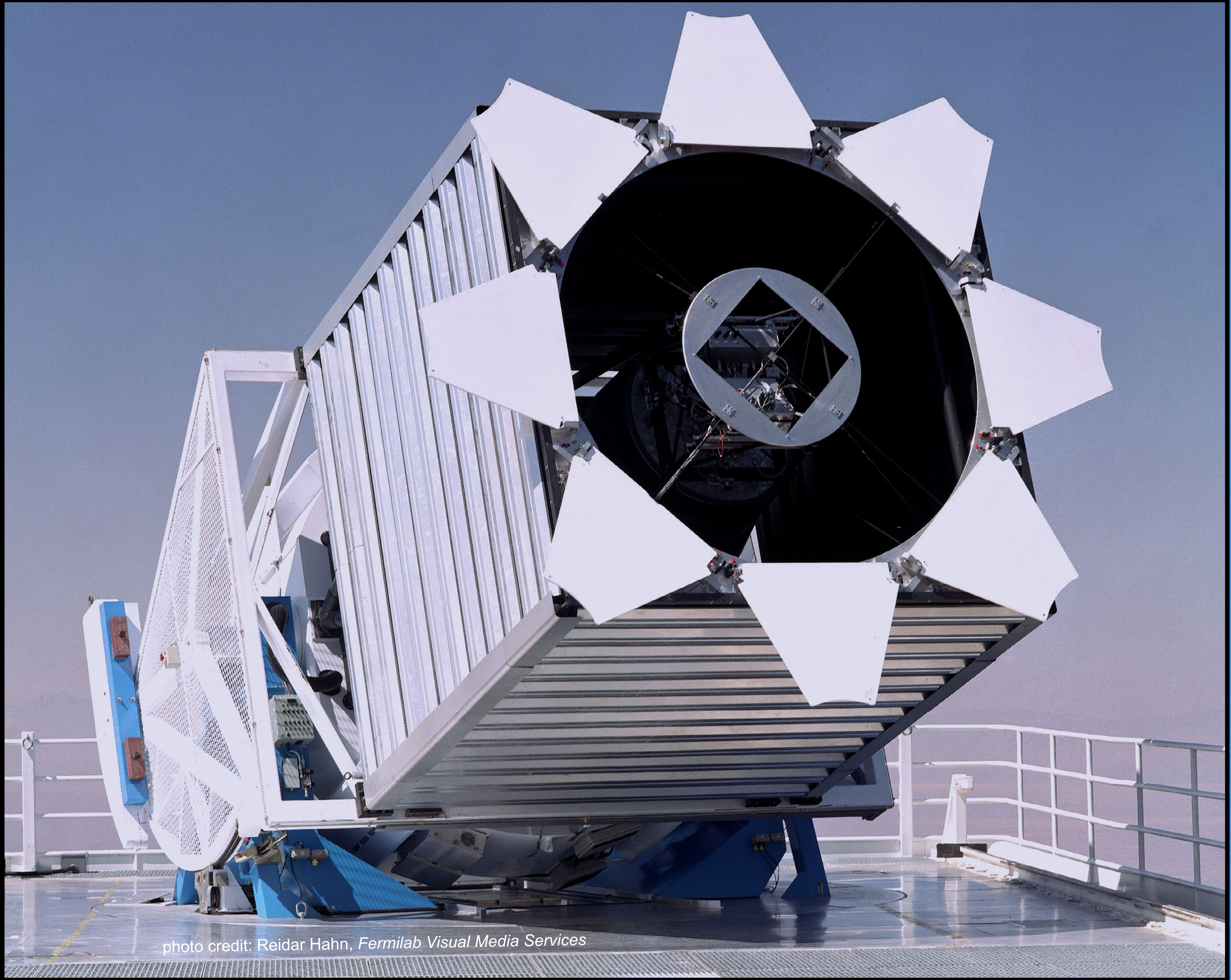

photo credit: Reidar Hahn, *Fermilab Visual Media Services*

😎

NO WORRIES,

SDSS HAS AN

AMAZING

TELESCOPE

AND A TEAM OF

EXCELLENT

ASTRONOMERS…

Empirical Galaxy-Size Distribution vs. Analytic Log-Normal Distribution Curve

$\mathrm{N} = 3{,}483\ (\sum n)$

$$f_X(r;\mu,\sigma) = \frac{1}{r\sigma\sqrt{2\pi}}\exp\left(-\frac{(\ln r-\mu)^2}{2\sigma^2}\right)$$

- ● Bin Count (galaxies)
- — Median Radius (4.05)
- — Mean Radius (4.73)
- ▨ PDF*: $f_X(r;\mu,\sigma)\cdot S$

$\mu = 1.3984$

$\sigma = 0.5593$

$S = 350$ (scaling constant)

* **P**robability **D**istribution **F**unction

Note: the vertical scale is >10× the $\bar{z}$ = 0.010 scale.

$\Delta r_{\text{bin}} = 0.1''$

$\bar{z}$ = 0.020

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Empirical Galaxy-Size Distribution vs. Analytic Log-Normal Distribution Curve

$\mu = 1.1179$
$\sigma = 0.4686$
$S = 800$

Note: the vertical scale is 2× the $\bar{z}$ = 0.020 scale.

$\Delta r_{\text{bin}} = 0.1''$

$\bar{z}$ = 0.040

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Empirical Galaxy-Size Distribution vs. Analytic Log-Normal Distribution Curve

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Empirical Galaxy-Size Distribution vs. Analytic Log-Normal Distribution Curve

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Empirical Inference

②

Galaxies have a log-normal size distribution.

Empirical Inference

③

That distribution is empirically observed to be consistent over the data set ($0.02 \leq z \leq 0.64$).

Empirical Inference

④

To very good approximation, the mean apparent galaxy size (*theta-bar*) in each redshift bin can be expected to represent the same standard rod (i.e., to be very nearly the same *intrinsic size* ℓ).

Inference | ˈinf(ə)rəns |
noun
a conclusion reached on the basis of evidence and reasoning: *researchers are entrusted with drawing inferences from the data.*

Galaxy Mean Radius ($\bar{\theta}_z$) Plotted For Each Redshift Bin (Black Squares)

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Empirical **Constant-Intrinsic-Galaxy-Size** Curve (linear fit to $\bar{\theta}_z$ data)

$\log\theta = -0.3749 \cdot \log z + 0.01355$

Pearson correlation coefficient: -0.9967

(–1 implies a *perfect* linear relationship.)

Empirical reference curve
(constant-intrinsic-galaxy-size)

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Model A

Einstein's metric —an exact solution to the Einstein field equations (EFE)

Recall

(page 23)

$$ds^2 = -\,dr^2 - R^2 \sin^2\left(\frac{r}{R}\right)\left[d\psi^2 + \sin^2(\psi)\,d\theta^2\right] \boxed{+\,c^2 dt^2}$$

1) The Universe is finite, yet has no boundary. ✓

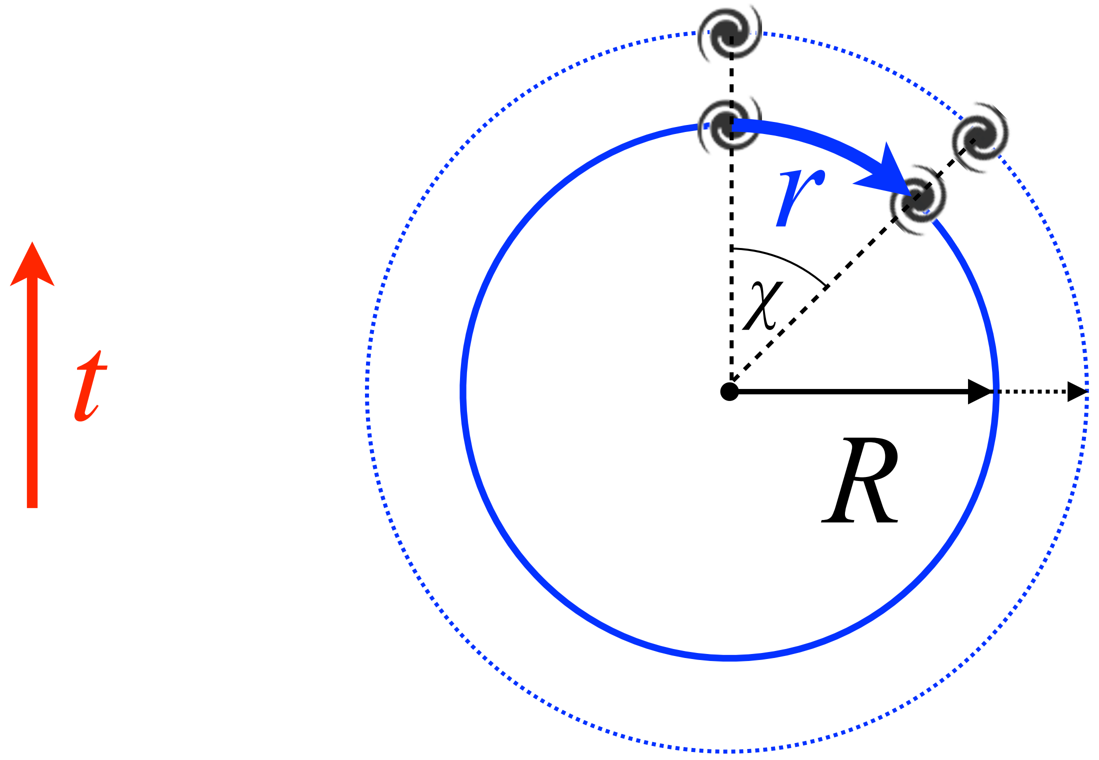
2) Time is *independent* of space in the metric.

Galaxy redshift & *time dilation* modeled as $dR/dt > 0$ (i.e., "expanding universe").

$$d\theta = d\Psi = 0$$

$$d\chi \equiv \frac{dr}{R}$$

$$D_C \propto \chi$$



Riemannian geometry ✓

vs.

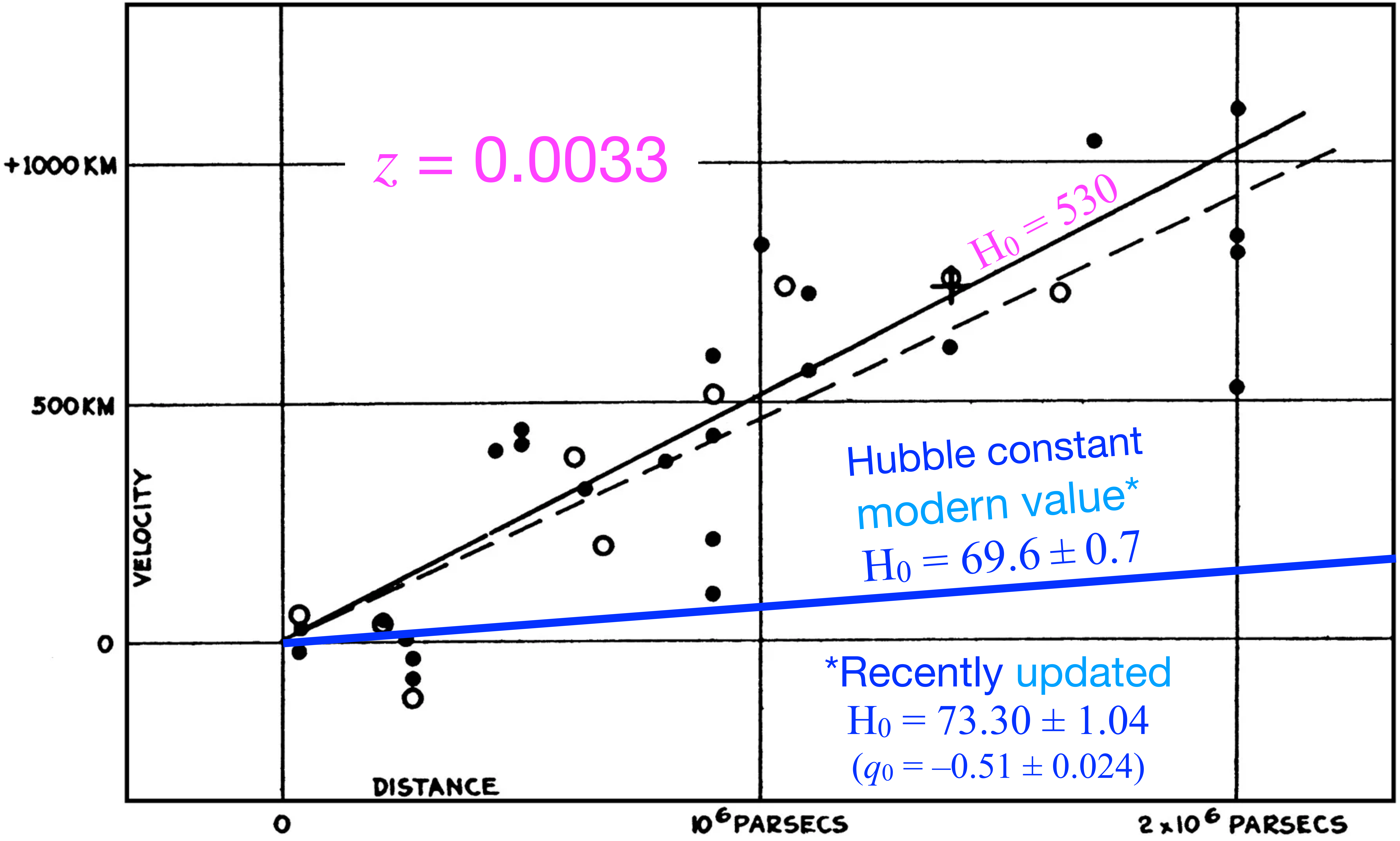
Euclidean geometry

$R \propto a$ (dimensionless cosmic scale factor)

A. Einstein, "Cosmological Considerations in the General Theory of Relativity", *SPAW*, 142 (1917).

Hubble Diagram (1929)

The historical foundation of the “expanding universe” paradigm.



$z = 0.0033$

$H_0 = 530$

Hubble constant
modern value*
$H_0 = 69.6 \pm 0.7$

*Recently updated
$H_0 = 73.30 \pm 1.04$
$(q_0 = -0.51 \pm 0.024)$

H_0 units
$\text{km s}^{-1}\ \text{Mpc}^{-1}$

Both H_0 values fit
the thick blue line.

E. Hubble,
“A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae”, *PNAS* **15**, 168 (1929).

Hubble's law:

(i.e., model)

$$v = H_0 D$$

$$v \approx cz \ (z \ll 1)$$

"Double the redshift→double the distance."

∴ Double the redshift→half the apparent size.

If this relationship does not hold, the Universe is *not* expanding.

petroR50_$\overline{gri}$

The data does not support the model.

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petroR50_$\overline{\text{gri}}$

[~2.4M measurements]

The data does not support the model (i.e., catastrophic* failure of the model)…

**irreconcilable*

As per differences in ‘measurements’ of (H_0, Ω_M, Ω_Λ), such variation has no appreciable effect on these curves.

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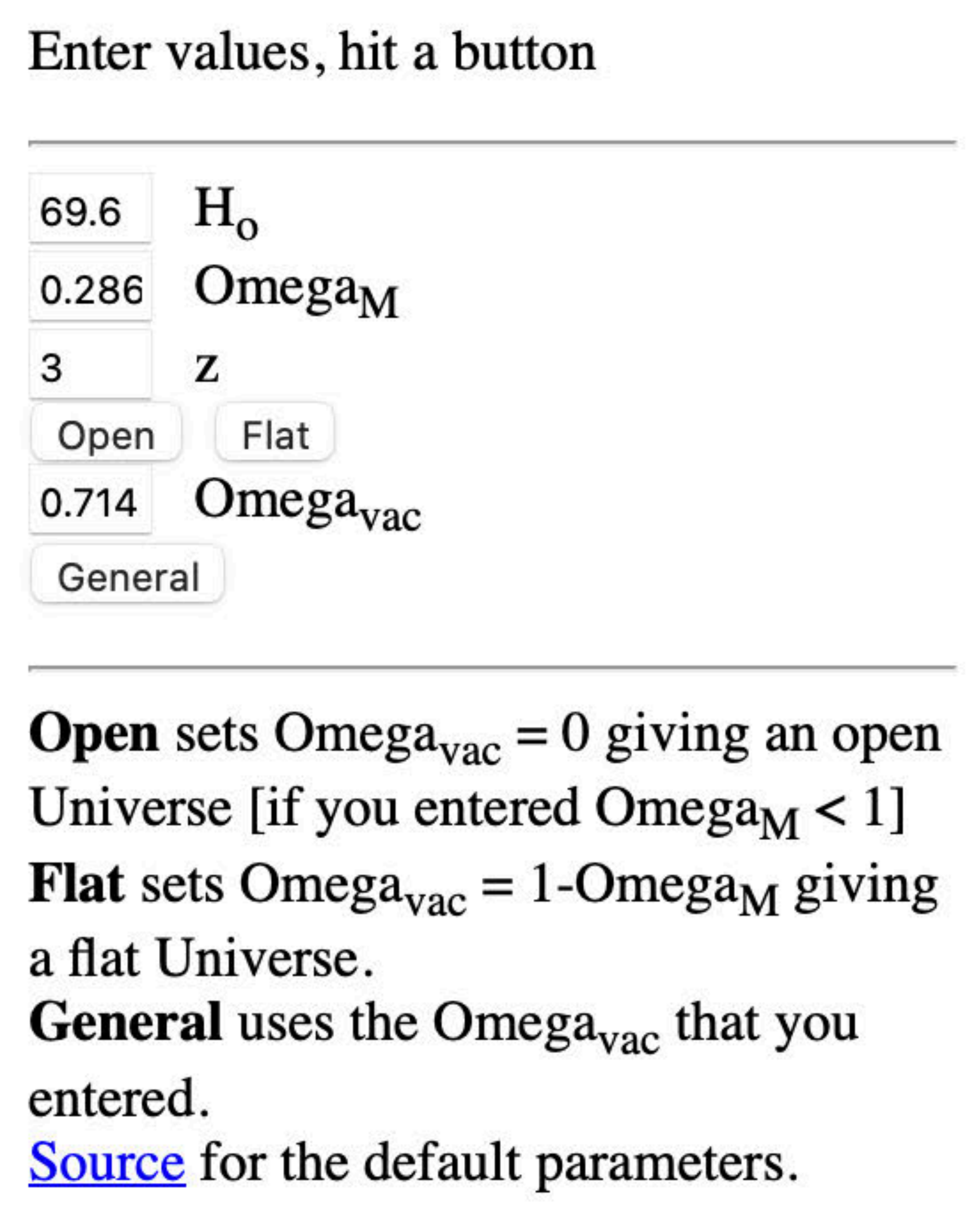


Enter values, hit a button

69.6 H_o

0.286 Omega_M

3 z

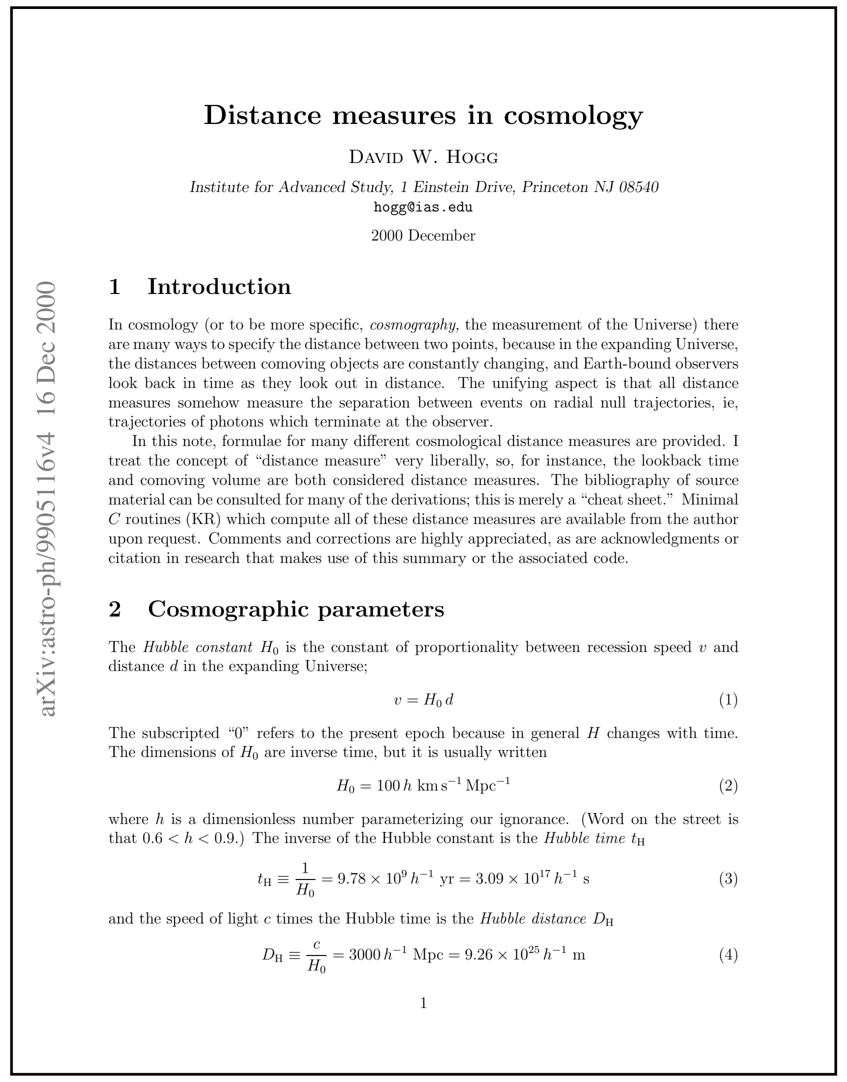
0.714 Omega_{vac}

Open sets $\mathrm{Omega}_{vac} = 0$ giving an open Universe [if you entered $\mathrm{Omega}_M < 1$]

Flat sets $\mathrm{Omega}_{vac} = 1-\mathrm{Omega}_M$ giving a flat Universe.

General uses the Omega_{vac} that you entered.

Source for the default parameters.



Distance measures in cosmology

David W. Hogg

Institute for Advanced Study, 1 Einstein Drive, Princeton NJ 08540
`hogg@ias.edu`

2000 December

arXiv:astro-ph/9905116v4 16 Dec 2000

1 Introduction

In cosmology (or to be more specific, *cosmography,* the measurement of the Universe) there are many ways to specify the distance between two points, because in the expanding Universe, the distances between comoving objects are constantly changing, and Earth-bound observers look back in time as they look out in distance. The unifying aspect is that all distance measures somehow measure the separation between events on radial null trajectories, ie, trajectories of photons which terminate at the observer.

In this note, formulae for many different cosmological distance measures are provided. I treat the concept of "distance measure" very liberally, so, for instance, the lookback time and comoving volume are both considered distance measures. The bibliography of source material can be consulted for many of the derivations; this is merely a "cheat sheet." Minimal *C* routines (KR) which compute all of these distance measures are available from the author upon request. Comments and corrections are highly appreciated, as are acknowledgments or citation in research that makes use of this summary or the associated code.

2 Cosmographic parameters

The *Hubble constant* H_0 is the constant of proportionality between recession speed v and distance d in the expanding Universe;

$$v = H_0\, d \tag{1}$$

The subscripted "0" refers to the present epoch because in general H changes with time. The dimensions of H_0 are inverse time, but it is usually written

$$H_0 = 100\, h\ \mathrm{km\,s^{-1}\,Mpc^{-1}} \tag{2}$$

where h is a dimensionless number parameterizing our ignorance. (Word on the street is that $0.6 < h < 0.9$.) The inverse of the Hubble constant is the *Hubble time* t_H

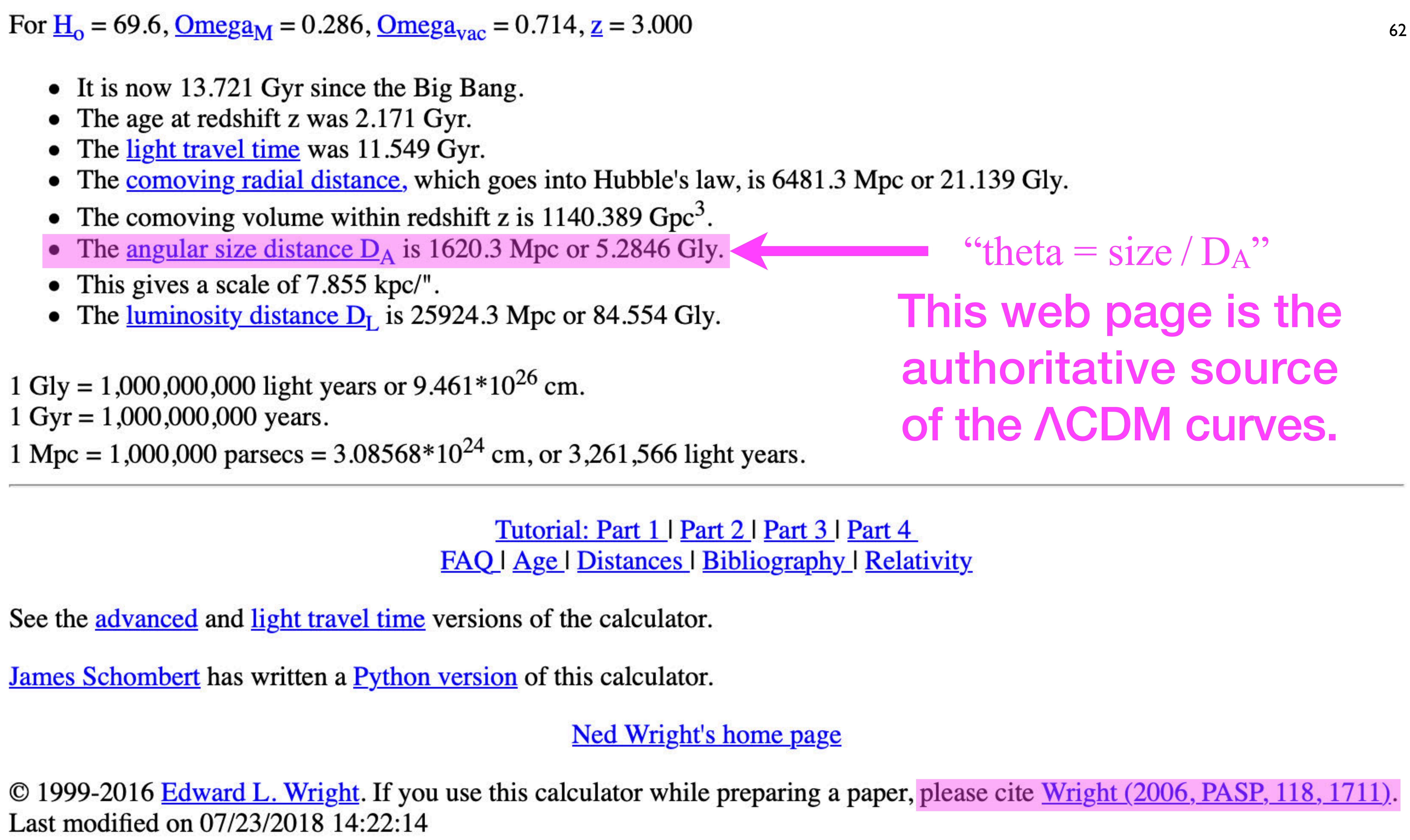
$$t_H \equiv \frac{1}{H_0} = 9.78 \times 10^9\, h^{-1}\ \mathrm{yr} = 3.09 \times 10^{17}\, h^{-1}\ \mathrm{s} \tag{3}$$

and the speed of light c times the Hubble time is the *Hubble distance* D_H

$$D_H \equiv \frac{c}{H_0} = 3000\, h^{-1}\ \mathrm{Mpc} = 9.26 \times 10^{25}\, h^{-1}\ \mathrm{m} \tag{4}$$

1

Also see: D. Hogg (2000)



For $H_o = 69.6$, $\mathrm{Omega}_M = 0.286$, $\mathrm{Omega}_{vac} = 0.714$, $z = 3.000$

- It is now 13.721 Gyr since the Big Bang.
- The age at redshift z was 2.171 Gyr.
- The light travel time was 11.549 Gyr.
- The comoving radial distance, which goes into Hubble's law, is 6481.3 Mpc or 21.139 Gly.
- The comoving volume within redshift z is 1140.389 Gpc^3.
- The angular size distance D_A is 1620.3 Mpc or 5.2846 Gly.
- This gives a scale of 7.855 kpc/".
- The luminosity distance D_L is 25924.3 Mpc or 84.554 Gly.

"theta = size / D_A"

1 Gly = 1,000,000,000 light years or 9.461×10^{26} cm.
1 Gyr = 1,000,000,000 years.
1 Mpc = 1,000,000 parsecs = 3.08568×10^{24} cm, or 3,261,566 light years.

This web page is the authoritative source of the ΛCDM curves.

Tutorial: Part 1 | Part 2 | Part 3 | Part 4
FAQ | Age | Distances | Bibliography | Relativity

See the advanced and light travel time versions of the calculator.

James Schombert has written a Python version of this calculator.

Ned Wright's home page

© 1999-2016 Edward L. Wright. If you use this calculator while preparing a paper, please cite Wright (2006, PASP, 118, 1711).
Last modified on 07/23/2018 14:22:14

https://astro.ucla.edu/~wright/CosmoCalc.html

There is no analytic solution to any prediction.

> “If it disagrees with experiment, it’s wrong. In that simple statement is the key to science. It doesn’t make a difference how beautiful your guess is. It doesn’t make any difference how smart you are, who made the guess, or what his name is; if it disagrees with experiment, it’s wrong. That’s all there is to it.”

– Richard P. Feynman, Cornell University Lecture, 1964 (1-minute video)

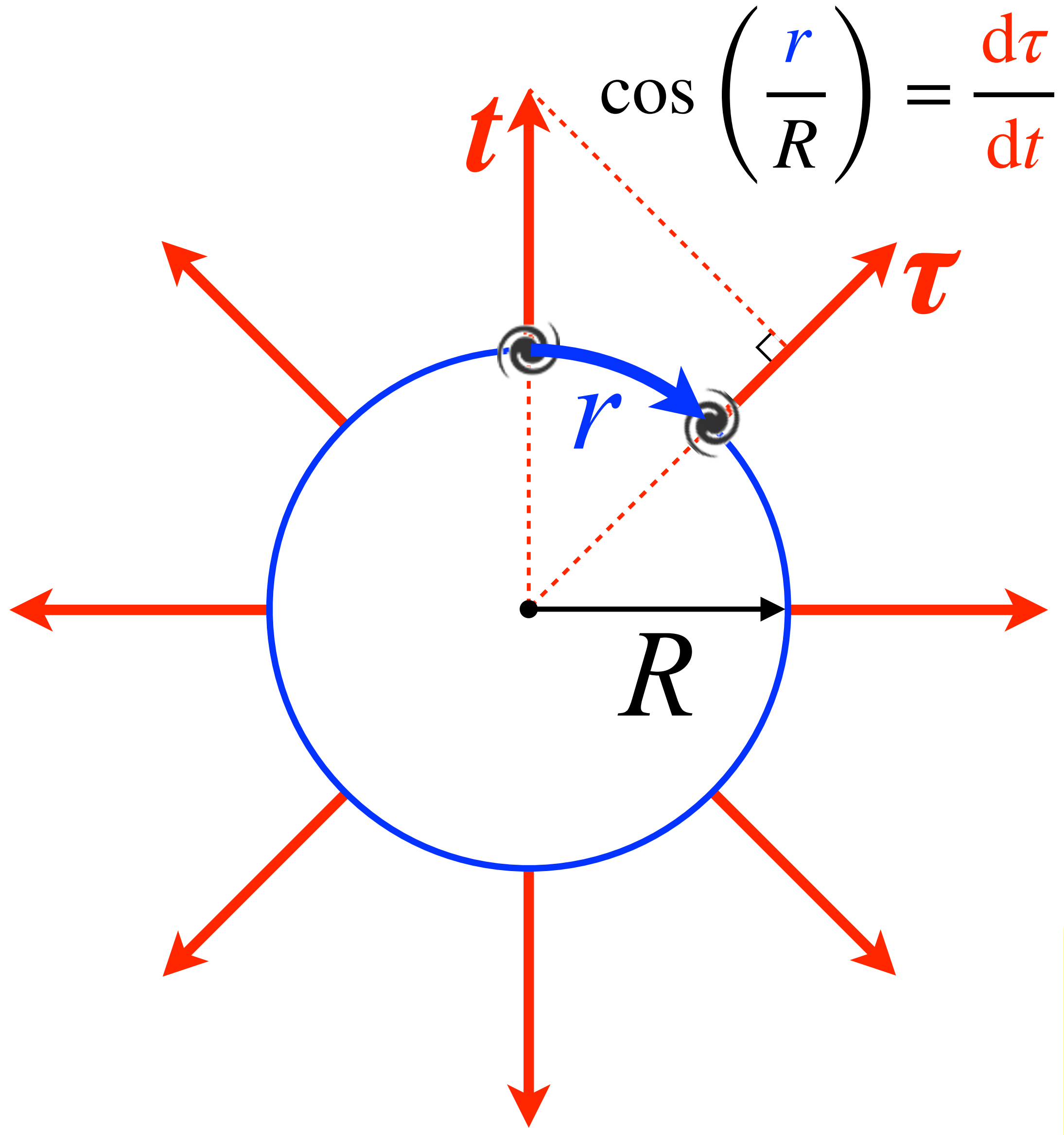
Model B

Willem de Sitter’s metric — a different exact solution to the EFE

Recall
(page 25)

$$ds^2 = -\,dr^2 - R^2\sin^2\left(\frac{r}{R}\right)\left[d\psi^2 + \sin^2(\psi)\,d\theta^2\right] + \overset{c^2 d\tau^2}{\boxed{\cos^2\left(\frac{r}{R}\right)c^2 dt^2}}$$

1) The Universe is finite, yet has no boundary.
2) Time is *dependent* on space in the metric.



$$\frac{dt}{d\tau} = \frac{1}{\cos\chi}$$

Local proper time is
a *geometric object.*

radians

$$\chi = \frac{r}{R}\left(\frac{\text{measured physical distance}}{\text{fixed cosmic radius }[\dot{R}=0]}\right)$$

$$z = \frac{1}{\cos\chi} - 1$$

Galaxy redshift & time dilation modeled
as relativistic temporal geometry ($\dot{R} = 0$).

$$\dot{R} \equiv \frac{dR}{dt} = 0$$

W. de Sitter,
“Einstein’s theory of gravitation and its astronomical consequences. Third paper”, *MNRAS* **78**, 3 (1917).

The tool implementing the mediation between theory and practice, between thought and observation, is mathematics. Mathematics builds the connecting bridges and is constantly enhancing their capabilities. Therefore it happens that our entire contemporary culture, in so far as it rests on intellectual penetration and utilization of nature, finds its foundations in mathematics.

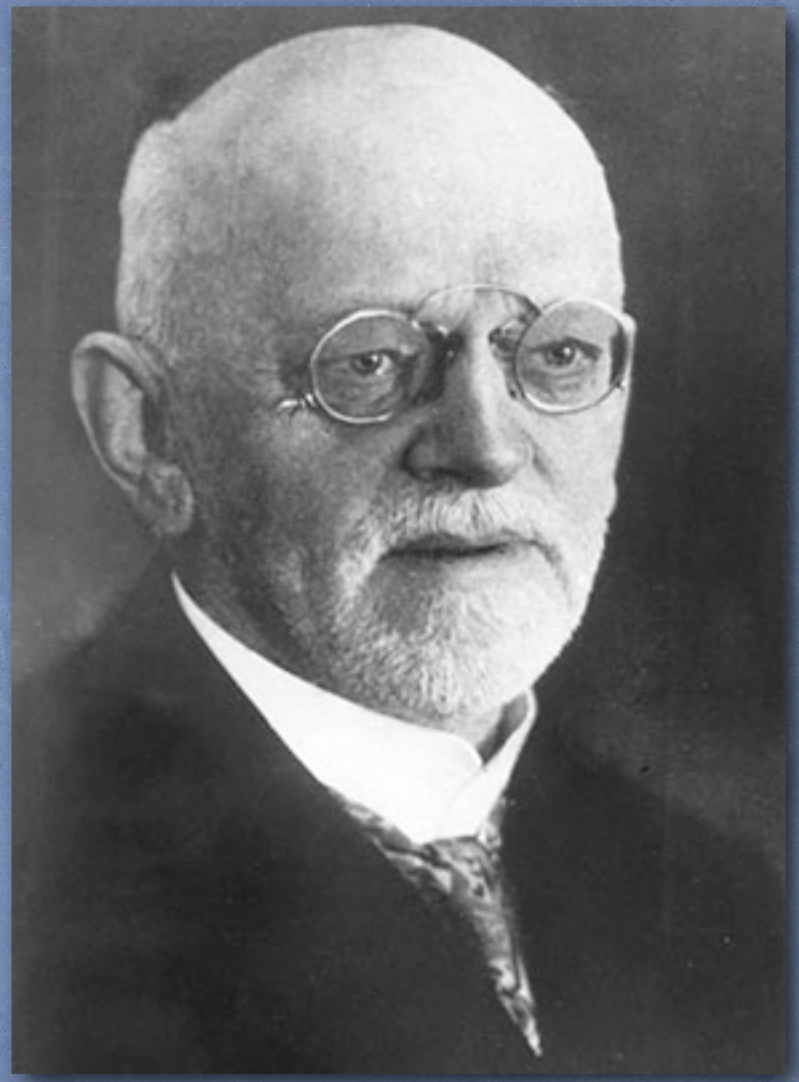
…

For us there is no ignorance, especially not, in my opinion, for the natural sciences.

Instead of this silly ignorance, on the contrary let our fate be:

"We must know, we will know."

– David Hilbert, *Preeminent 20th-century mathematician* (1862–1943)


David Hilbert

Source: *Talk given by David Hilbert in Königsberg*, Fall 1930; translation by Amelia and Joe Ball.

A direct derivation from an exact solution of the Einstein field equations

$$ds^2 = -\,dr^2 - R^2 \sin^2\left(\frac{r}{R}\right)\left[d\psi^2 + \sin^2(\psi)\, d\theta^2\right] + \boxed{\cos^2\left(\frac{r}{R}\right) c^2 dt^2}$$

If this is true…

This theta-z formula is an a priori theoretical prediction; it was developed *prior to* knowledge of the SDSS data.

then this is true.

$$\theta(z) = C_\ell \left(1 - \frac{1}{(z+1)^2}\right)^{-\frac{1}{2}} \quad , \quad C_\ell \propto \ell \text{ (intrinsic size)}$$

The shape of the curve is determined exclusively by z.

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> “A mathematical model, theory, or conjecture is more likely to be right and less likely to be the product of wishful thinking if it relies on few free parameters and is consistent with large amounts of data.”

– WIKIPEDIA , “Free parameter”

RTG predictive model

$$\theta(z) = C_\ell \left(1 - \frac{1}{(z+1)^2}\right)^{-\frac{1}{2}} \quad , \quad C_\ell = 1$$

(Why not an arbitrary number?!)

petroR50_$\overline{\text{gri}}$

There are *no free parameters* to modify the curve;
C_ℓ merely shifts the curve up or down on the θ-axis.

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Petrosian radius (`petro`**`Rad`**) vs. half-light radius data (`petroR50`)

$$\theta(z) = C_\ell \left(1 - \frac{1}{(z+1)^2}\right)^{-\frac{1}{2}} , \quad C_\ell = 2$$

petroRad_$\overline{\text{gri}}$

That $C_\ell = 2$, rather than some random real number, is thought-provoking. 🤯

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Redshift Bin Statistics for `petroRad_`$\overline{\texttt{gri}}$

Minimum Redshift $z_{\min}$	Maximum Redshift $z_{\max}$	**Average Redshift** $\bar{z} = \sum z \div \mathrm{N}$	**Galaxy count** N	**StdDev[$\ln(r)$]** σ	$\overline{\ln(r)}$ μ	**Mean Radius** $\bar{\theta} = \mathrm{e}^{\left(\mu+\frac{\sigma^2}{2}\right)}$	**Median Radius** e^{μ}	**Standard Deviation** e^{σ}
0.0090	0.0110	**0.010**	387	0.6952	2.2769	**12.41**	4.56	2.00
0.0180	0.0220	**0.020**	3,341	0.5807	2.1822	**10.49**	4.05	1.79
0.0380	0.0420	**0.040**	7,973	0.4842	1.9025	**7.54**	3.06	1.62
0.0760	0.0840	**0.080**	38,020	0.3998	1.6147	**5.44**	2.27	1.49
0.1520	0.1680	**0.160**	34,497	0.3145	1.5330	**4.87**	2.05	1.37
0.3040	0.3360	**0.320**	28,399	0.2709	1.2752	**3.71**	1.57	1.31
0.6100	0.6800	**0.640**	6,759	0.2394	0.8882	**2.50**	1.18	1.27

Note: The average $\bar{\theta}$ error for the `petroRad` dataset is **6.2% vs. 3.6%** for `petroR50`.

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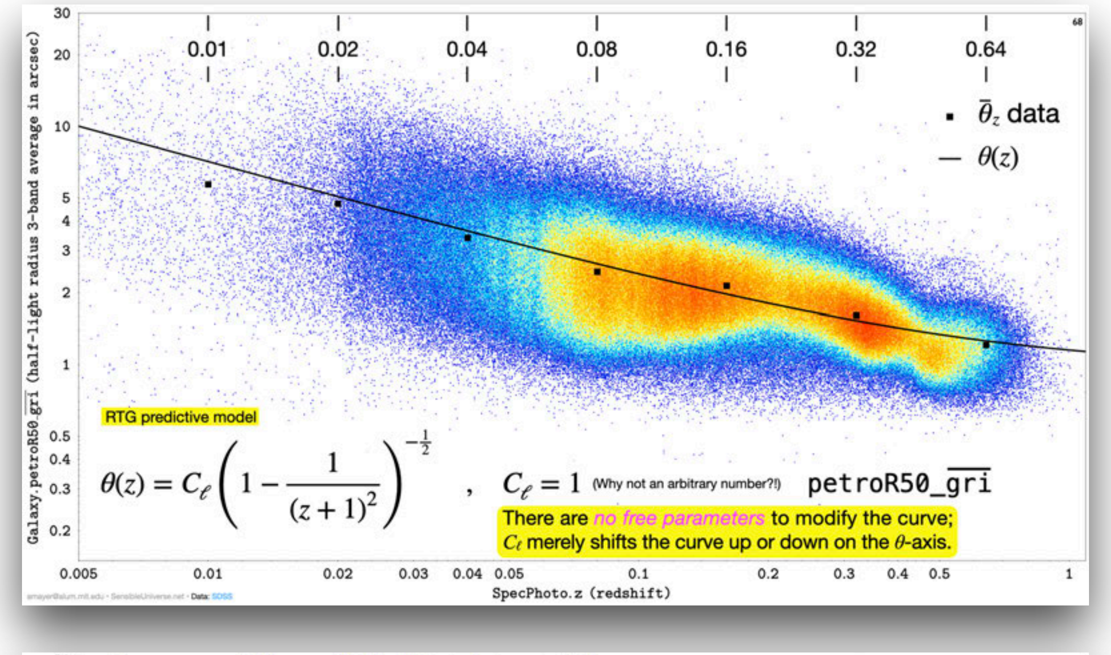
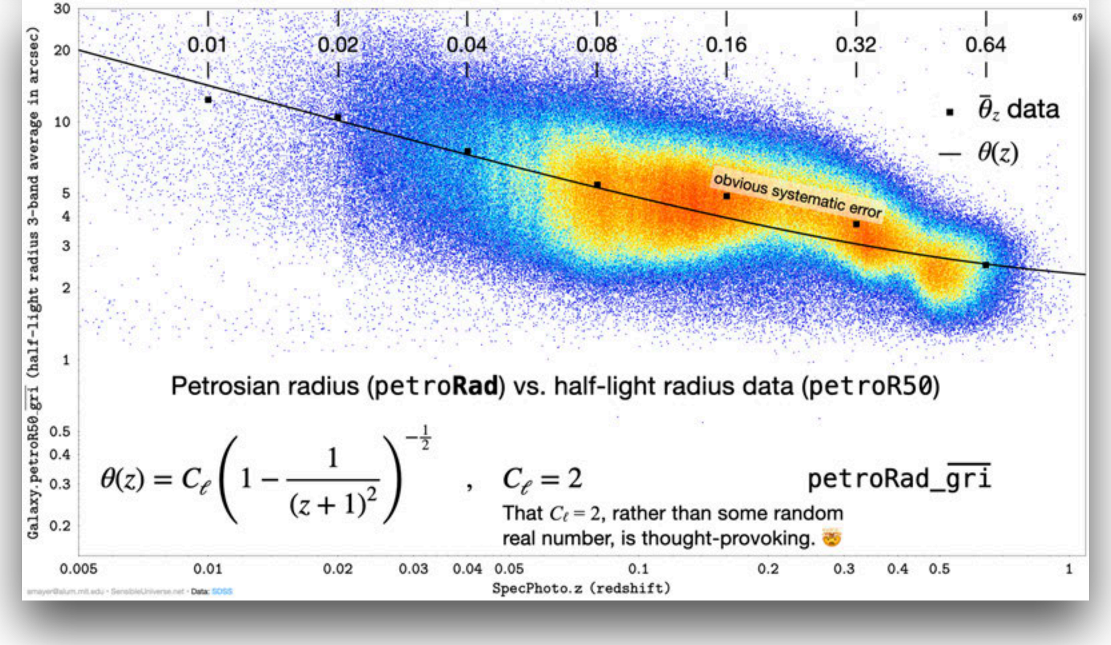
To be clear, the new model…

pages 68–69





- is an a priori analytic curve that rests on the fundamental principles of general relativity;
- derives directly from Willem de Sitter’s 1917 exact solution of the field equations;
- contains no free parameters: $\theta = f(z)$, exclusively;
- provides a nearly-perfect fit to statistically-significant empirical data whose accuracy is incontrovertible.

According to the accepted *principles of science*, the remarkable correlation of the model to the data exhibited in pages 68 and 69 cannot possibly be coincidental. Anyone who would make such a claim in an attempt to dismiss the clear evidence falsifying the standard model, while also supplanting it with the presented new model, is insincere and is obviously pursuing an unethical agenda.

Such behavior is according to the author’s prior experience.

Es ist immer angenehm, über strenge Lösungen einfacher Form zu verfügen.

“It is always pleasant to have exact solutions in simple form at your disposal.”

– Karl Schwarzschild, “On the Gravitational Field of a Mass Point According to Einstein’s Theory”;
In: Proceedings of the Royal Prussian Academy of Sciences Meeting (3 February 1916), p. 190.

English translation; arXiv:physics/9905030 [physics.hist-ph]

The Complete Set of Empirically-Accurate Cosmological Predictive Equations

RTG model

A logically consistent set:

1 iff 2 iff 3

(1) Theta-z

$$\theta(z) = C_R \left(1 - \frac{1}{(z+1)^2}\right)^{-\frac{1}{2}}$$ radians

to be shown…

(2) Redshift-volume

$$S^3(z) = C_V \cdot \left[\cos^{-1}\left(\frac{1}{z+1}\right) - \left(\frac{1}{(z+1)^2} - \frac{1}{(z+1)^4}\right)^{\frac{1}{2}}\right]$$ arbitrary units

to be shown…

(3) Redshift-magnitude

$$m(z) = C_M - 2.5 \cdot \log\left(\frac{1}{4\pi\left[(z+1)^4 - (z+1)^2\right]}\right) + \underbrace{\epsilon_\lambda \cos^{-1}\left(\frac{1}{z+1}\right)}_{\text{IGM extinction*}}$$ mags

$^*\dfrac{\mathrm{d}\epsilon_\lambda}{\mathrm{d}z} = 0$ yields a linear approximation.

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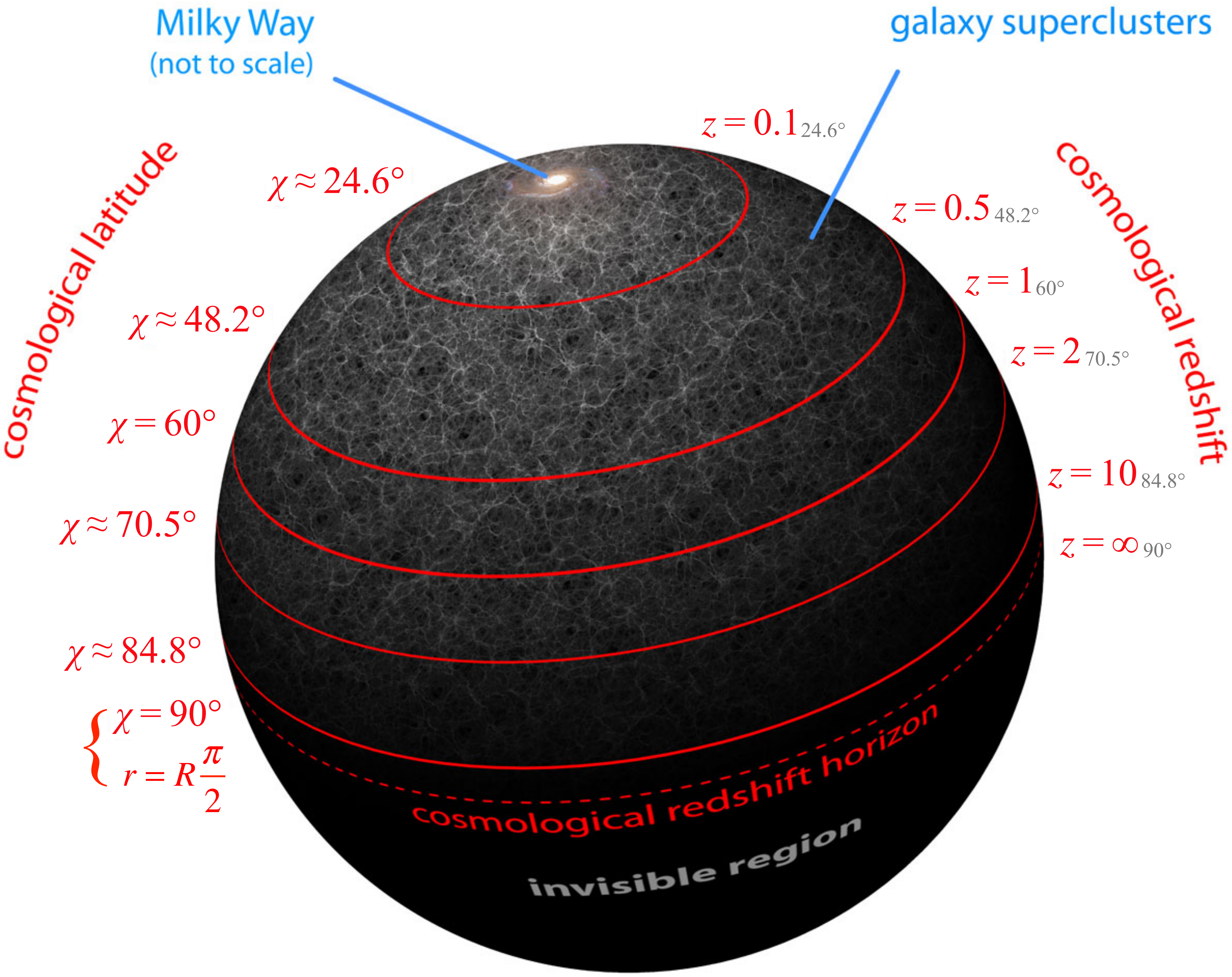
A complete cosmological map of the $\mathbb{S}^2$ surface *locally* defined by Galactic latitude $b = 0$ (i.e., the Galactic plane)

$$\chi = \cos^{-1}\left(\frac{1}{z+1}\right)$$

$$z = \frac{1}{\cos\chi} - 1$$



$$\chi \equiv \frac{r}{R}$$

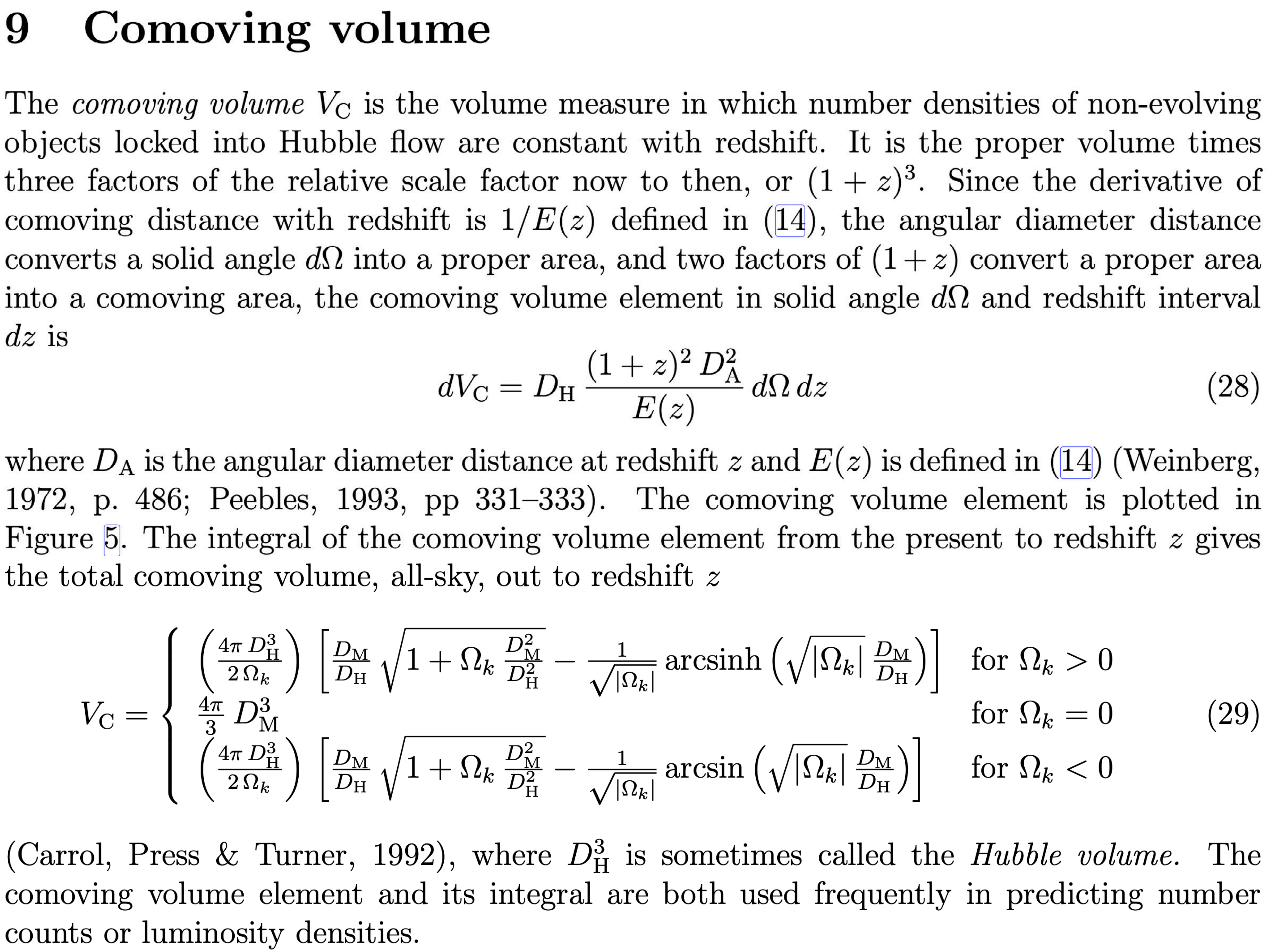
$$r = R\cos^{-1}\left(\frac{1}{z+1}\right)$$

$z = \infty$

@ horizon

$(\chi = \pi/2)$

Graphic by Fabio Basile after an original rendering by Hollin Calloway.



9 Comoving volume

The *comoving volume* $V_{\rm C}$ is the volume measure in which number densities of non-evolving objects locked into Hubble flow are constant with redshift. It is the proper volume times three factors of the relative scale factor now to then, or $(1+z)^3$. Since the derivative of comoving distance with redshift is $1/E(z)$ defined in (14), the angular diameter distance converts a solid angle $d\Omega$ into a proper area, and two factors of $(1+z)$ convert a proper area into a comoving area, the comoving volume element in solid angle $d\Omega$ and redshift interval dz is

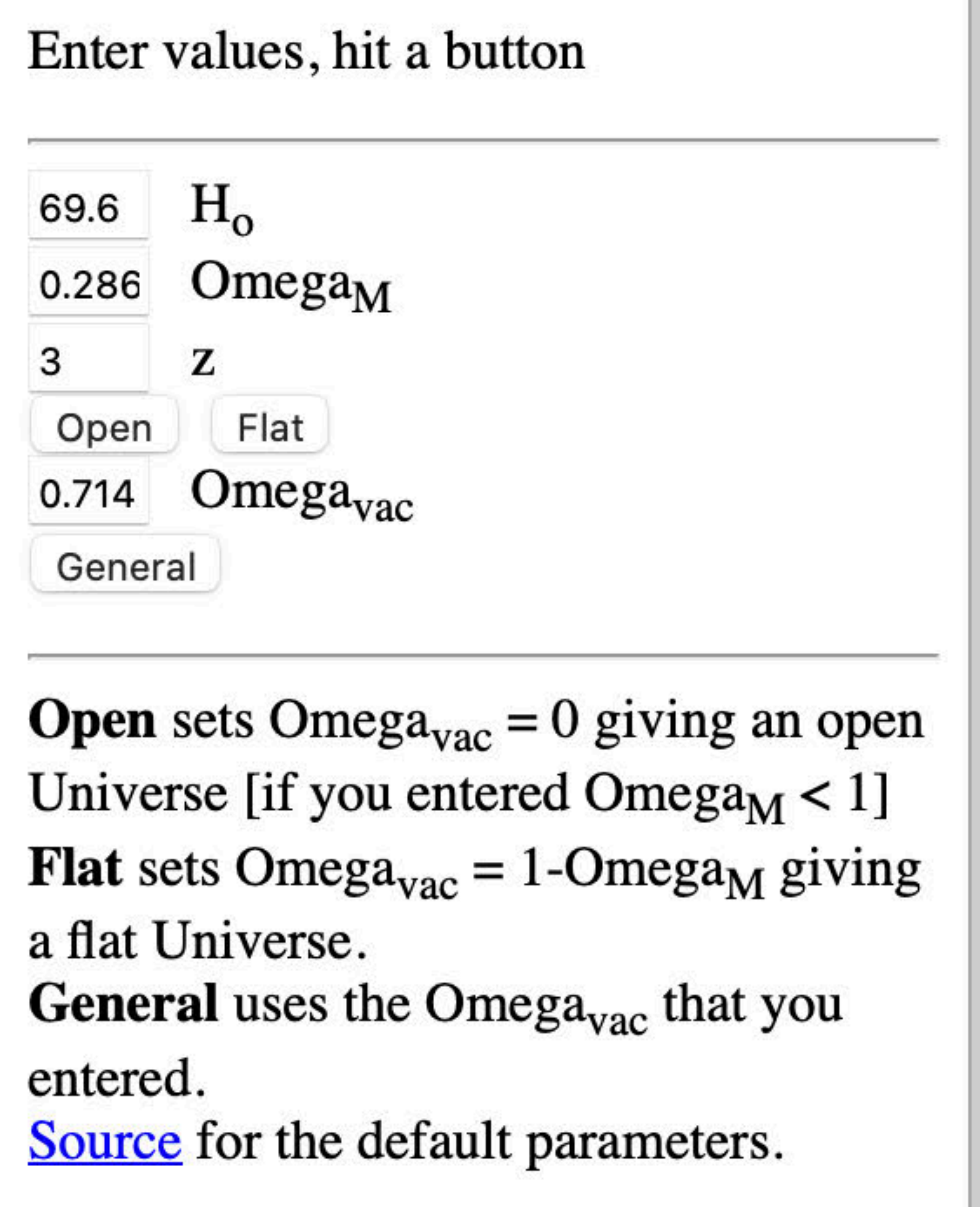
$$dV_{\rm C} = D_{\rm H}\,\frac{(1+z)^2\,D_{\rm A}^2}{E(z)}\,d\Omega\,dz \tag{28}$$

where $D_{\rm A}$ is the angular diameter distance at redshift z and $E(z)$ is defined in (14) (Weinberg, 1972, p. 486; Peebles, 1993, pp 331–333). The comoving volume element is plotted in Figure 5. The integral of the comoving volume element from the present to redshift z gives the total comoving volume, all-sky, out to redshift z

$$V_{\rm C} = \begin{cases} \left(\frac{4\pi\,D_{\rm H}^3}{2\,\Omega_k}\right)\left[\frac{D_{\rm M}}{D_{\rm H}}\sqrt{1+\Omega_k\,\frac{D_{\rm M}^2}{D_{\rm H}^2}} - \frac{1}{\sqrt{|\Omega_k|}}\,\mathrm{arcsinh}\left(\sqrt{|\Omega_k|}\,\frac{D_{\rm M}}{D_{\rm H}}\right)\right] & \text{for } \Omega_k > 0 \\ \frac{4\pi}{3}\,D_{\rm M}^3 & \text{for } \Omega_k = 0 \\ \left(\frac{4\pi\,D_{\rm H}^3}{2\,\Omega_k}\right)\left[\frac{D_{\rm M}}{D_{\rm H}}\sqrt{1+\Omega_k\,\frac{D_{\rm M}^2}{D_{\rm H}^2}} - \frac{1}{\sqrt{|\Omega_k|}}\,\arcsin\left(\sqrt{|\Omega_k|}\,\frac{D_{\rm M}}{D_{\rm H}}\right)\right] & \text{for } \Omega_k < 0 \end{cases} \tag{29}$$

(Carrol, Press & Turner, 1992), where $D_{\rm H}^3$ is sometimes called the *Hubble volume*. The comoving volume element and its integral are both used frequently in predicting number counts or luminosity densities.

David W. Hogg, "Distance measured in cosmology", *Institute for Advanced Study, Princeton* (2000).



Enter values, hit a button

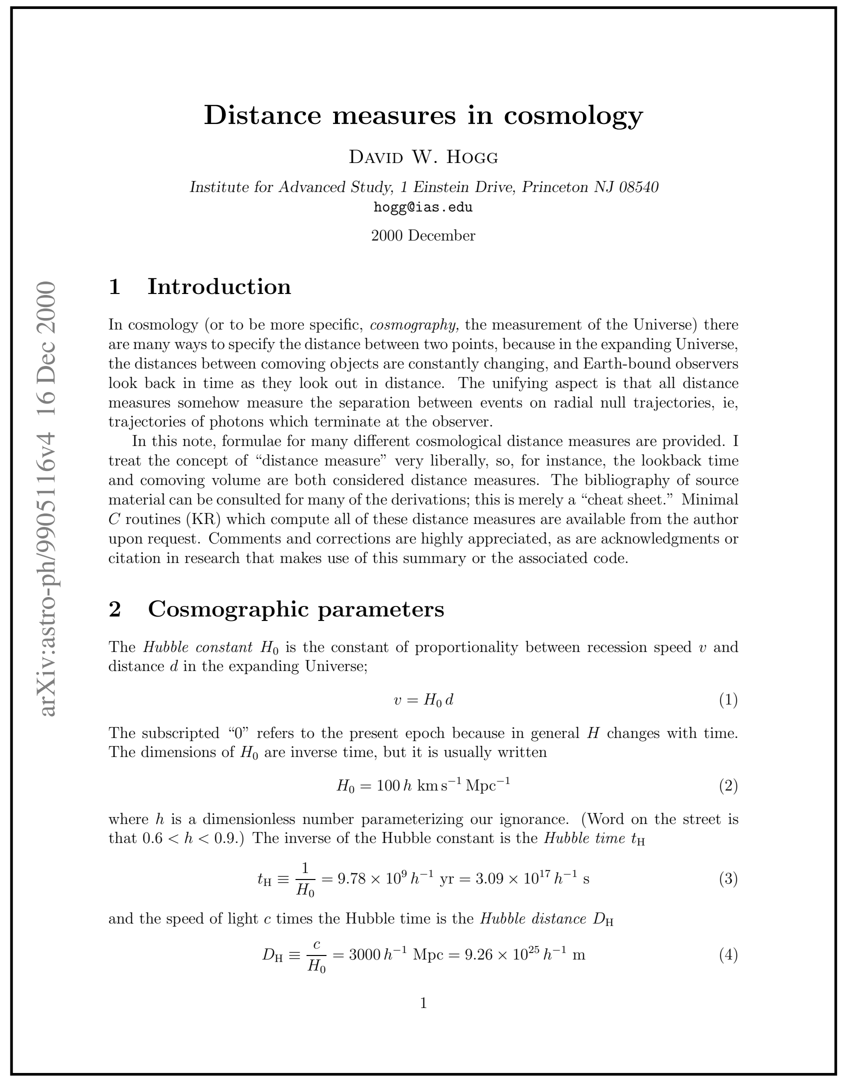
69.6 H_o

0.286 $Omega_M$

3 z

0.714 $Omega_{vac}$

Open sets $Omega_{vac} = 0$ giving an open Universe [if you entered $Omega_M < 1$]
Flat sets $Omega_{vac} = 1-Omega_M$ giving a flat Universe.
General uses the $Omega_{vac}$ that you entered.
Source for the default parameters.



Distance measures in cosmology

David W. Hogg

Institute for Advanced Study, 1 Einstein Drive, Princeton NJ 08540
`hogg@ias.edu`

2000 December

arXiv:astro-ph/9905116v4 16 Dec 2000

1 Introduction

In cosmology (or to be more specific, *cosmography,* the measurement of the Universe) there are many ways to specify the distance between two points, because in the expanding Universe, the distances between comoving objects are constantly changing, and Earth-bound observers look back in time as they look out in distance. The unifying aspect is that all distance measures somehow measure the separation between events on radial null trajectories, ie, trajectories of photons which terminate at the observer.

In this note, formulae for many different cosmological distance measures are provided. I treat the concept of "distance measure" very liberally, so, for instance, the lookback time and comoving volume are both considered distance measures. The bibliography of source material can be consulted for many of the derivations; this is merely a "cheat sheet." Minimal *C* routines (KR) which compute all of these distance measures are available from the author upon request. Comments and corrections are highly appreciated, as are acknowledgments or citation in research that makes use of this summary or the associated code.

2 Cosmographic parameters

The *Hubble constant* H_0 is the constant of proportionality between recession speed v and distance d in the expanding Universe;

$$v = H_0 \, d \tag{1}$$

The subscripted "0" refers to the present epoch because in general H changes with time. The dimensions of H_0 are inverse time, but it is usually written

$$H_0 = 100 \, h \ \mathrm{km\,s^{-1}\,Mpc^{-1}} \tag{2}$$

where h is a dimensionless number parameterizing our ignorance. (Word on the street is that $0.6 < h < 0.9$.) The inverse of the Hubble constant is the *Hubble time* t_H

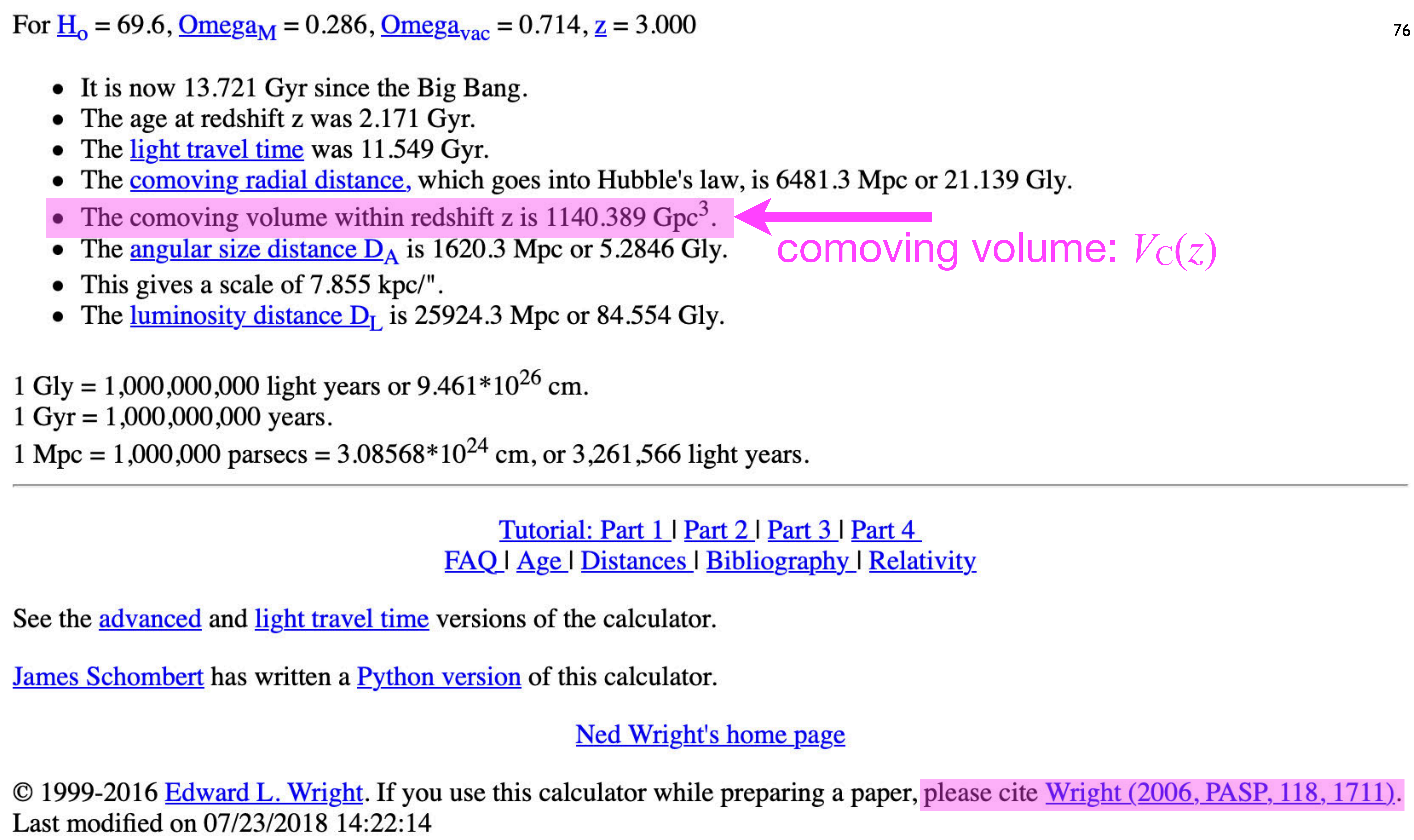
$$t_H \equiv \frac{1}{H_0} = 9.78 \times 10^9 \, h^{-1} \ \mathrm{yr} = 3.09 \times 10^{17} \, h^{-1} \ \mathrm{s} \tag{3}$$

and the speed of light c times the Hubble time is the *Hubble distance* D_H

$$D_H \equiv \frac{c}{H_0} = 3000 \, h^{-1} \ \mathrm{Mpc} = 9.26 \times 10^{25} \, h^{-1} \ \mathrm{m} \tag{4}$$

1

Also see: D. Hogg (2000)



For $H_o = 69.6$, $Omega_M = 0.286$, $Omega_{vac} = 0.714$, $z = 3.000$

- It is now 13.721 Gyr since the Big Bang.
- The age at redshift z was 2.171 Gyr.
- The light travel time was 11.549 Gyr.
- The comoving radial distance, which goes into Hubble's law, is 6481.3 Mpc or 21.139 Gly.
- The comoving volume within redshift z is 1140.389 Gpc^3.
- The angular size distance D_A is 1620.3 Mpc or 5.2846 Gly.
- This gives a scale of 7.855 kpc/".
- The luminosity distance D_L is 25924.3 Mpc or 84.554 Gly.

comoving volume: $V_C(z)$

1 Gly = 1,000,000,000 light years or $9.461*10^{26}$ cm.
1 Gyr = 1,000,000,000 years.
1 Mpc = 1,000,000 parsecs = $3.08568*10^{24}$ cm, or 3,261,566 light years.

Tutorial: Part 1 | Part 2 | Part 3 | Part 4
FAQ | Age | Distances | Bibliography | Relativity

See the advanced and light travel time versions of the calculator.

James Schombert has written a Python version of this calculator.

Ned Wright's home page

© 1999-2016 Edward L. Wright. If you use this calculator while preparing a paper, please cite Wright (2006, PASP, 118, 1711).
Last modified on 07/23/2018 14:22:14

https://astro.ucla.edu/~wright/CosmoCalc.html

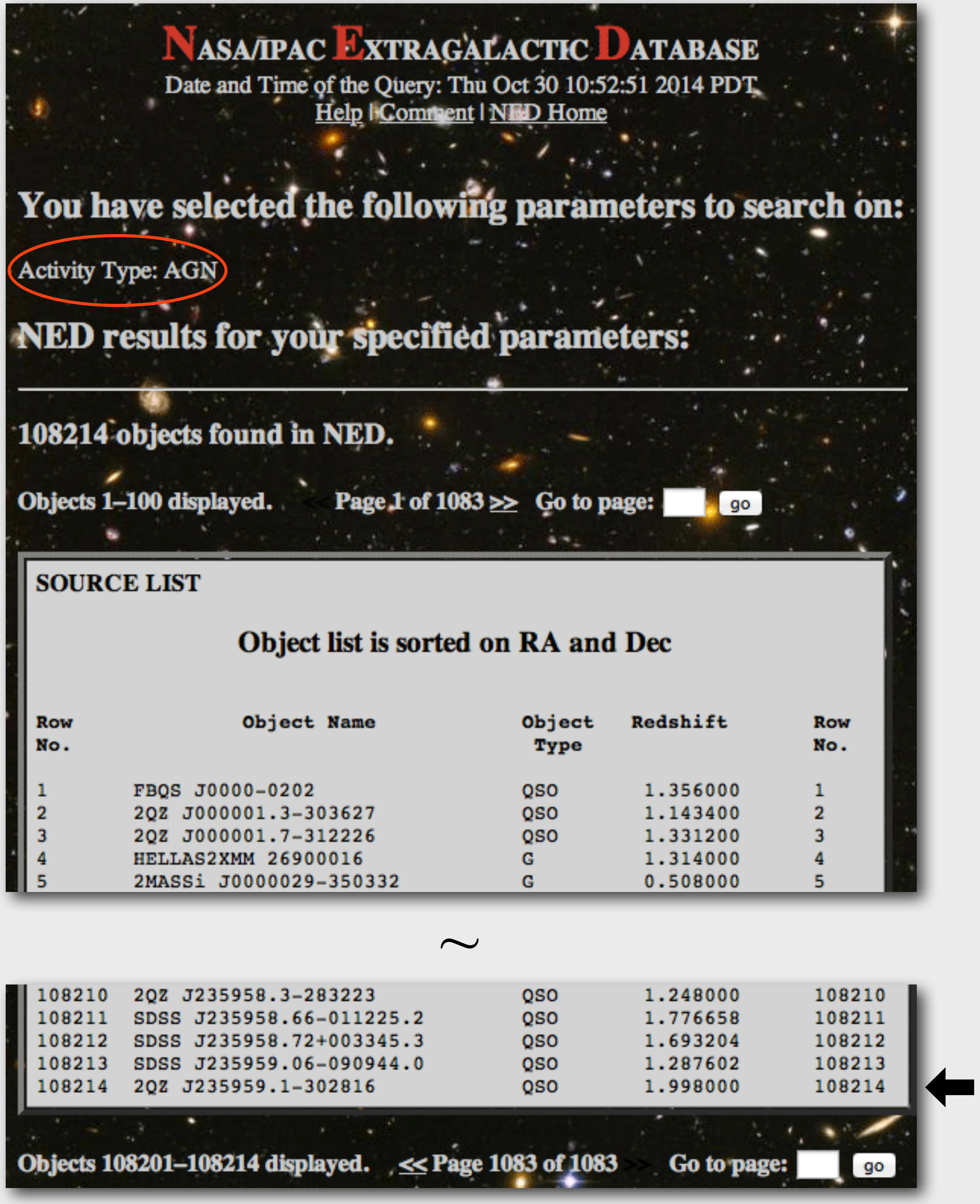
Space-density of active galactic nuclei

A small percentage of galaxies host an active galactic nucleus (AGN), which has a much higher luminosity than normal; the brightest AGN are observed at very high redshift (z>6), so these galaxies are an ideal observable with which to confront theoretical predictions of galaxy space density, including testable assumptions concerning galaxy evolution over lookback time.

To counteract any survey selection effects, data for ~108k AGN is sourced from the NASA/IPAC Extragalactic Database (NED); SDSS data constitutes about 72% of the graphed NED AGN dataset, with the balance sourced from numerous other surveys…

NED AGN

Click *image* for source data,
here for precompiled datafile.



NASA/IPAC EXTRAGALACTIC DATABASE
Date and Time of the Query: Thu Oct 30 10:52:51 2014 PDT
Help | Comment | NED Home

You have selected the following parameters to search on:

Activity Type: AGN

NED results for your specified parameters:

108214 objects found in NED.

Objects 1–100 displayed. **Page 1 of 1083 >>** **Go to page:** go

SOURCE LIST

Object list is sorted on RA and Dec

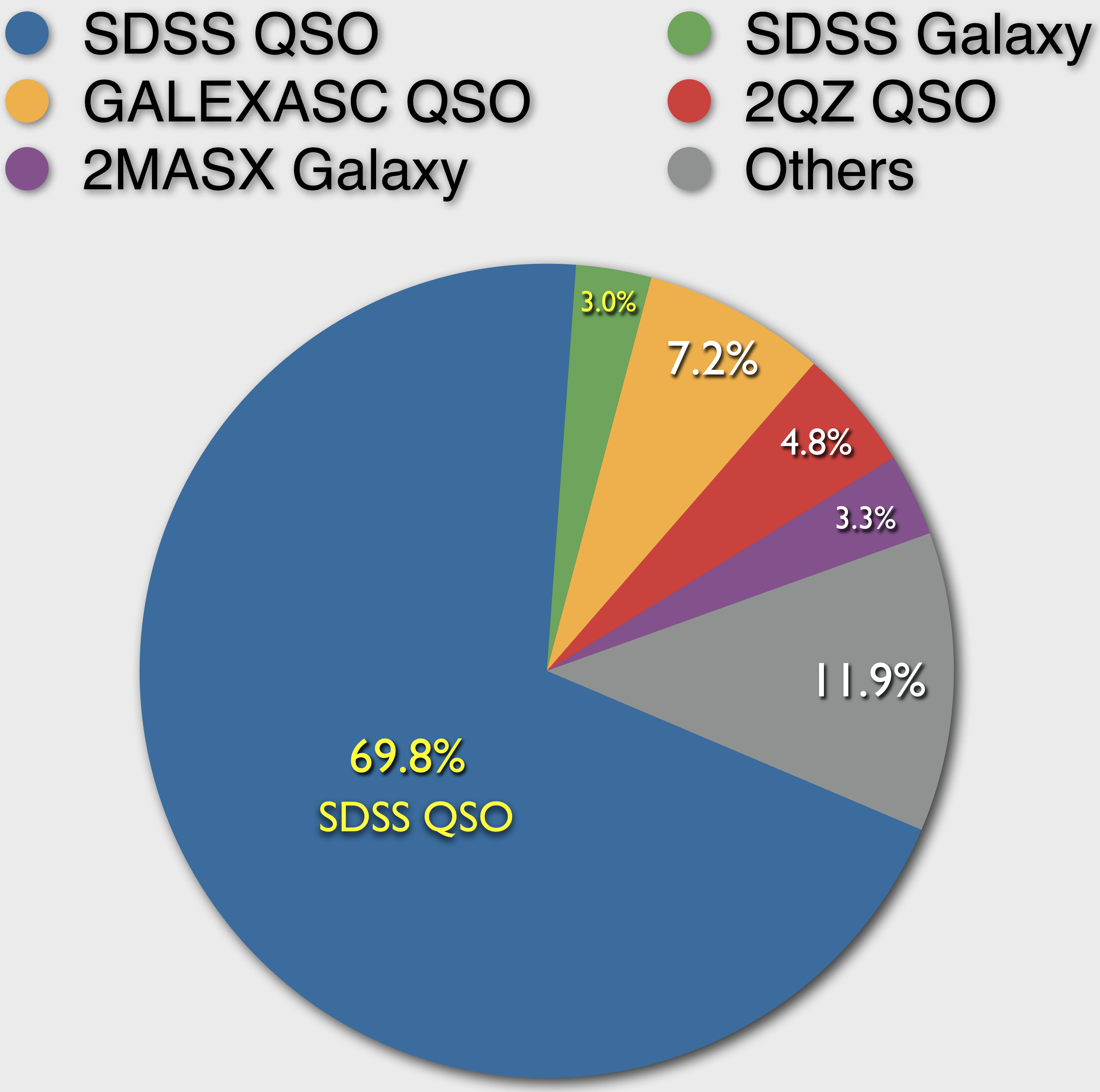
```
Row                Object Name               Object   Redshift        Row
No.                                           Type                    No.

1       FBQS J0000-0202                      QSO        1.356000      1
2       2QZ J000001.3-303627                 QSO        1.143400      2
3       2QZ J000001.7-312226                 QSO        1.331200      3
4       HELLAS2XMM 26900016                  G          1.314000      4
5       2MASSi J0000029-350332               G          0.508000      5
```

~

```
108210  2QZ J235958.3-283223                 QSO        1.248000      108210
108211  SDSS J235958.66-011225.2             QSO        1.776658      108211
108212  SDSS J235958.72+003345.3             QSO        1.693204      108212
108213  SDSS J235959.06-090944.0             QSO        1.287602      108213
108214  2QZ J235959.1-302816                 QSO        1.998000      108214
```

Objects 108201–108214 displayed. **<< Page 1083 of 1083** **Go to page:** go

⬅ 108,214 AGN



Note: 308 AGN have no redshift measurement, and 4 have blueshifts (MESSIER {081, 090, 098}, NGC 0404).

amayer@alum.mit.edu • SensibleUniverse.net

ΛCDM comoving volume V_C compared to cumulative AGN population

To intercept the two curves, the next page will use a new, *arbitrary* unit of measure, the VSmoot, which is 3.326E5 ÷ 180 = 1,847.778 Mpc³…

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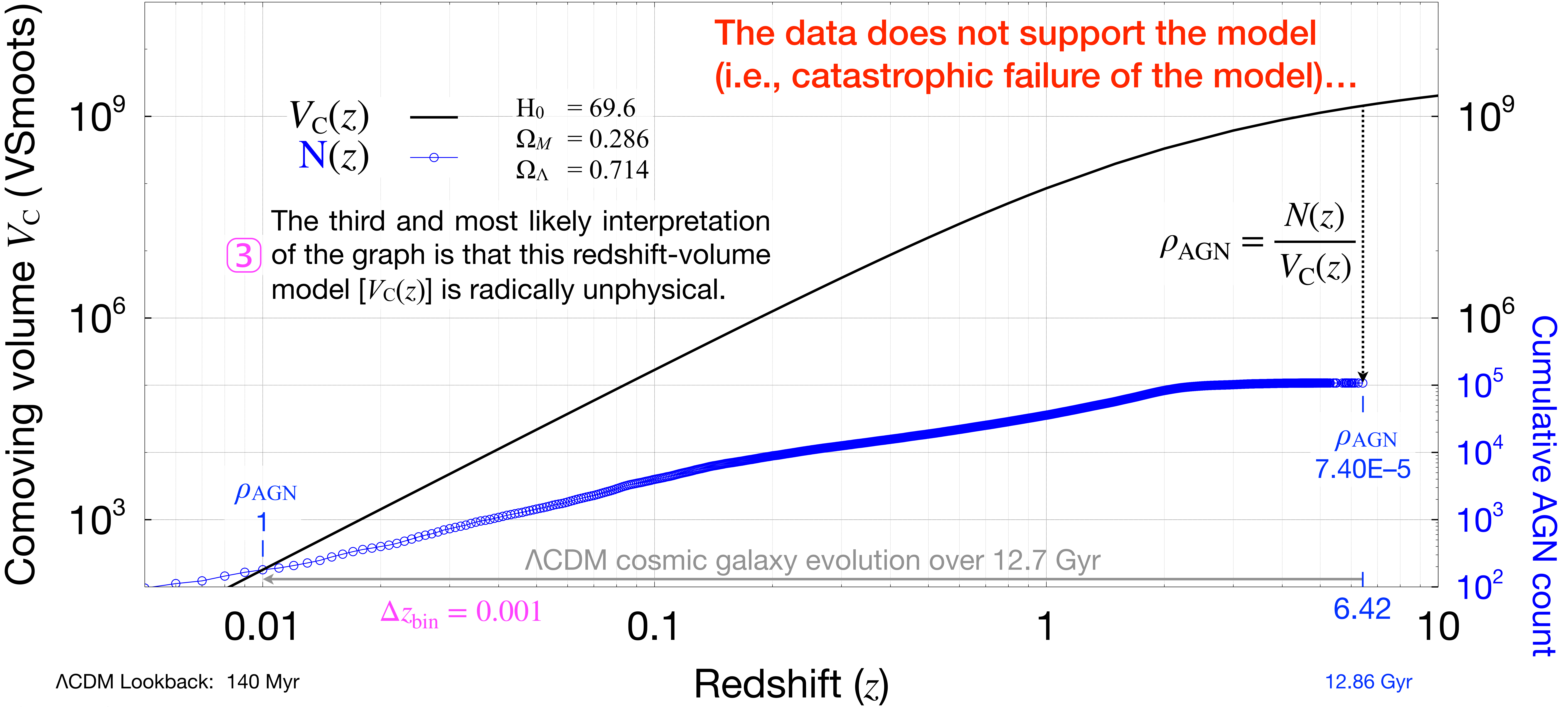
1 ΛCDM: over time, AGN space density increases by ~4 orders of magnitude.

2 Another possible interpretation of the graph, is that ≪1% of AGN that exist at higher redshift are observed and counted by the various astronomical surveys.



The data does not support the model (i.e., catastrophic failure of the model)…

3 The third and most likely interpretation of the graph is that this redshift-volume model [$V_C(z)$] is radically unphysical.

$$\rho_{AGN} = \frac{N(z)}{V_C(z)}$$

$\Delta z_{bin} = 0.001$

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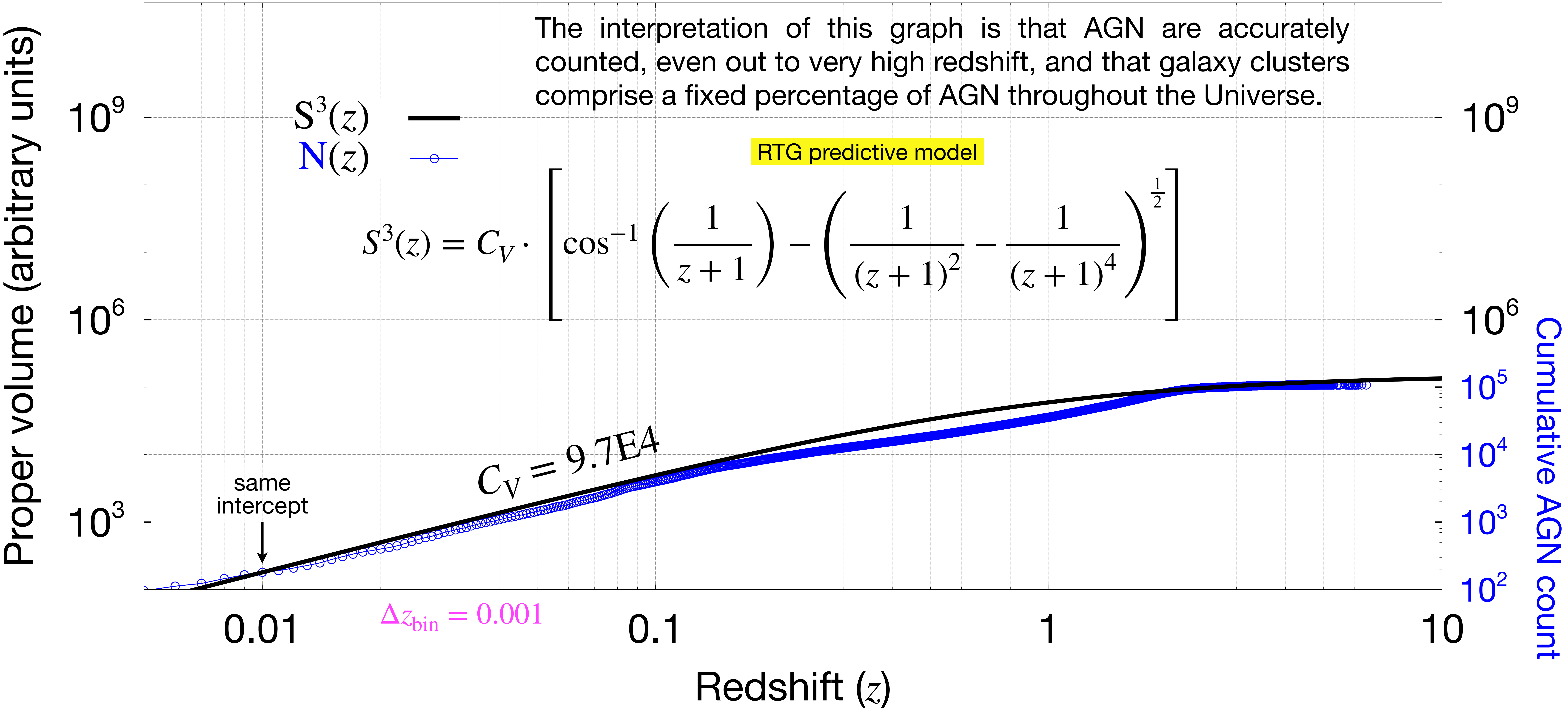
S^3 represents the volumetric ‘surface’ of a Riemannian 3-sphere

The fit of this a priori theoretical predictive curve to the empirical AGN population data is equally remarkable to that for the theta-z data; there are no free parameters available to achieve this fit.



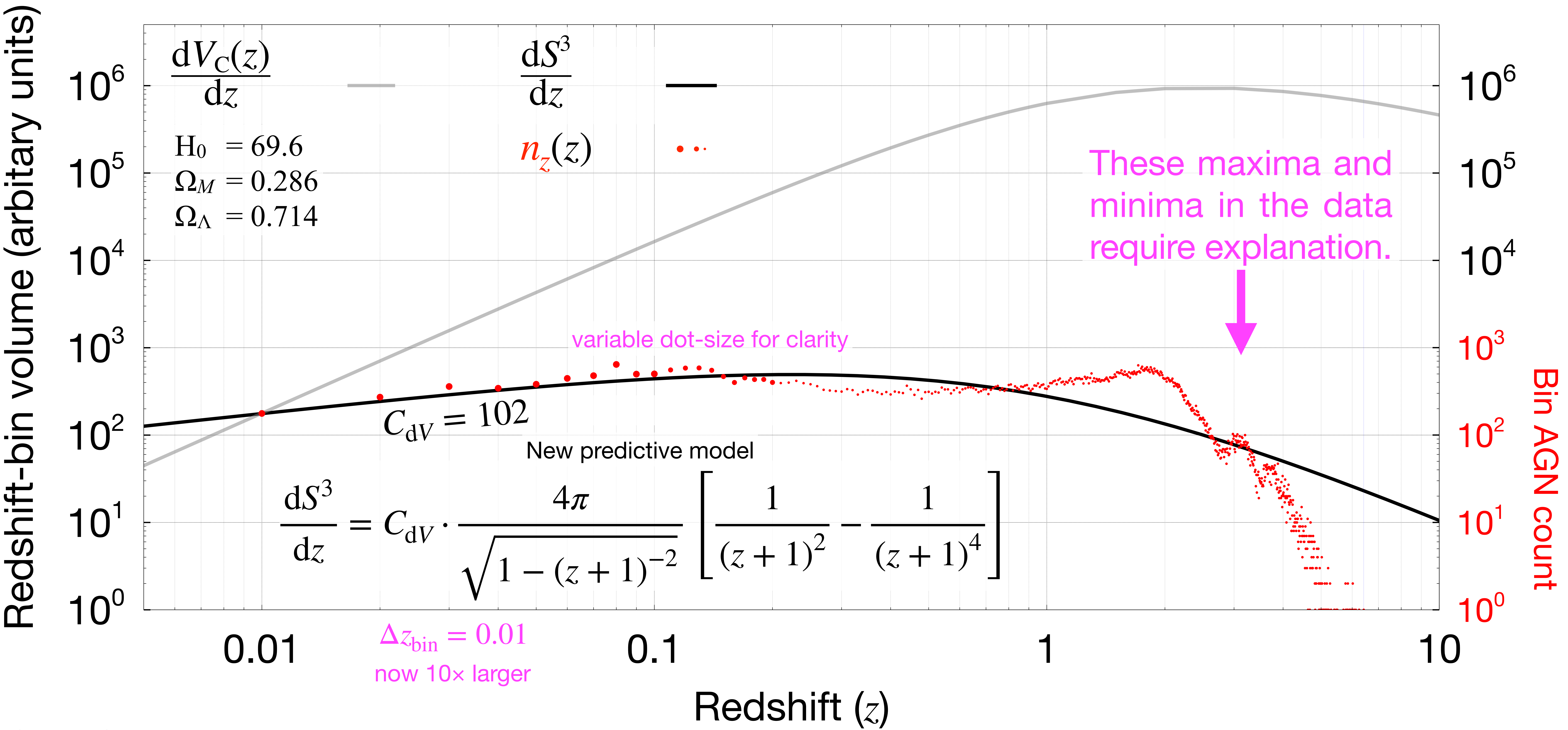
The interpretation of this graph is that AGN are accurately counted, even out to very high redshift, and that galaxy clusters comprise a fixed percentage of AGN throughout the Universe.

RTG predictive model

$$S^3(z) = C_V \cdot \left[\cos^{-1}\left(\frac{1}{z+1}\right) - \left(\frac{1}{(z+1)^2} - \frac{1}{(z+1)^4}\right)^{\frac{1}{2}} \right]$$

Modeled volume element versus AGN bin count with z

$$\frac{\mathrm{d}V_\mathrm{C}}{\mathrm{d}z} = 4\pi D_H \frac{(z+1)^2 D_A^2}{E(z)} \quad , \quad D_H = \frac{c}{H_0} \quad , \quad E(z) = \sqrt{\Omega_M(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda} \quad , \quad \Omega_M + \Omega_k + \Omega_\Lambda = 1$$



$H_0 = 69.6$
$\Omega_M = 0.286$
$\Omega_\Lambda = 0.714$

$C_\mathrm{dV} = 102$

These maxima and minima in the data require explanation.

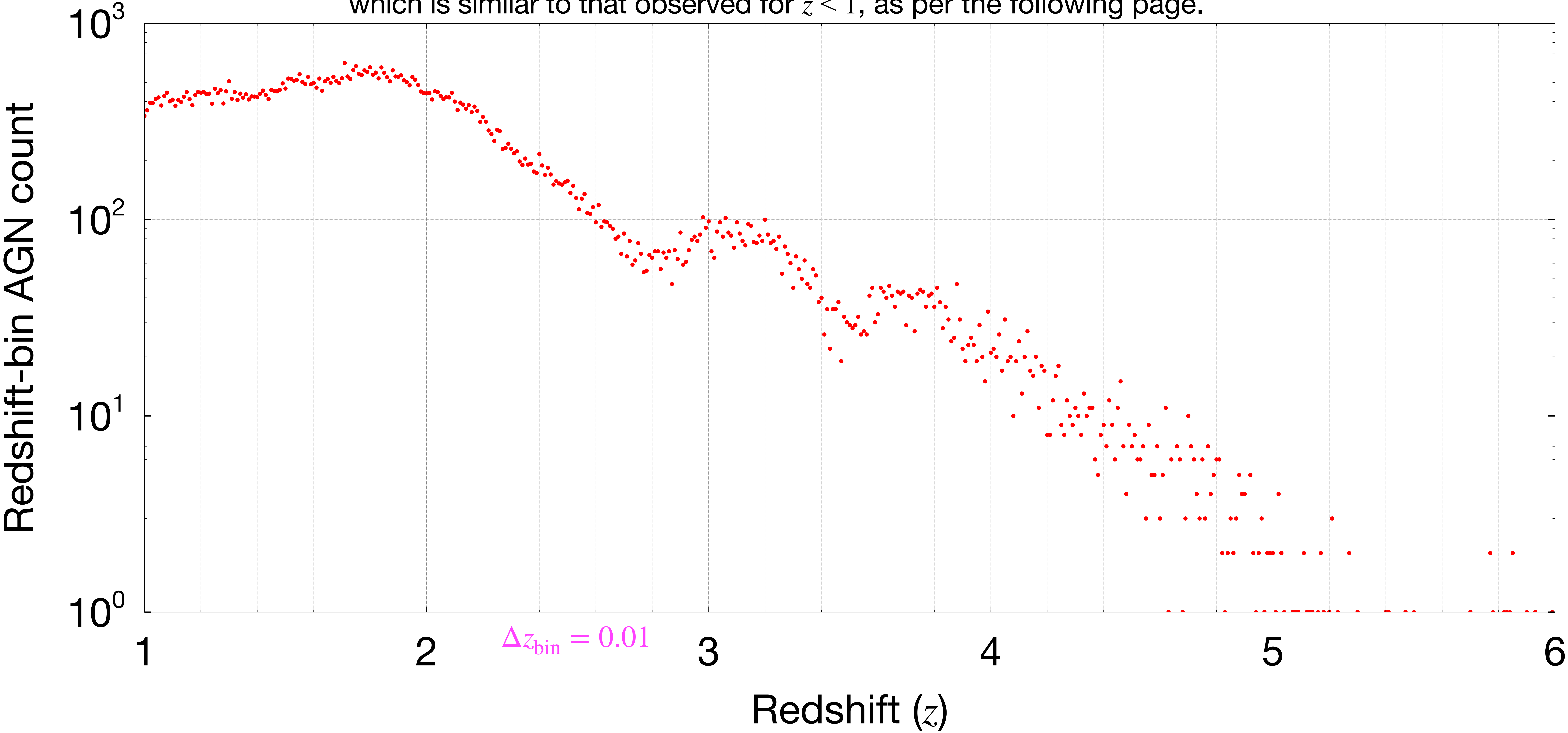
New predictive model

$$\frac{\mathrm{d}S^3}{\mathrm{d}z} = C_\mathrm{dV} \cdot \frac{4\pi}{\sqrt{1-(z+1)^{-2}}} \left[\frac{1}{(z+1)^2} - \frac{1}{(z+1)^4} \right]$$

$\Delta z_\mathrm{bin} = 0.01$
now 10× larger

Log-linear plot of AGN bin count showing detail

The observed periodicity ($1 \leq z \leq 4$) is indicative of variation in local galaxy population density at the largest cosmic distance scales, which is similar to that observed for $z < 1$, as per the following page.



amayer@alum.mit.edu • SensibleUniverse.net • Data: NED

Linear-log plot of SDSS and 2dF-Survey galaxy counts

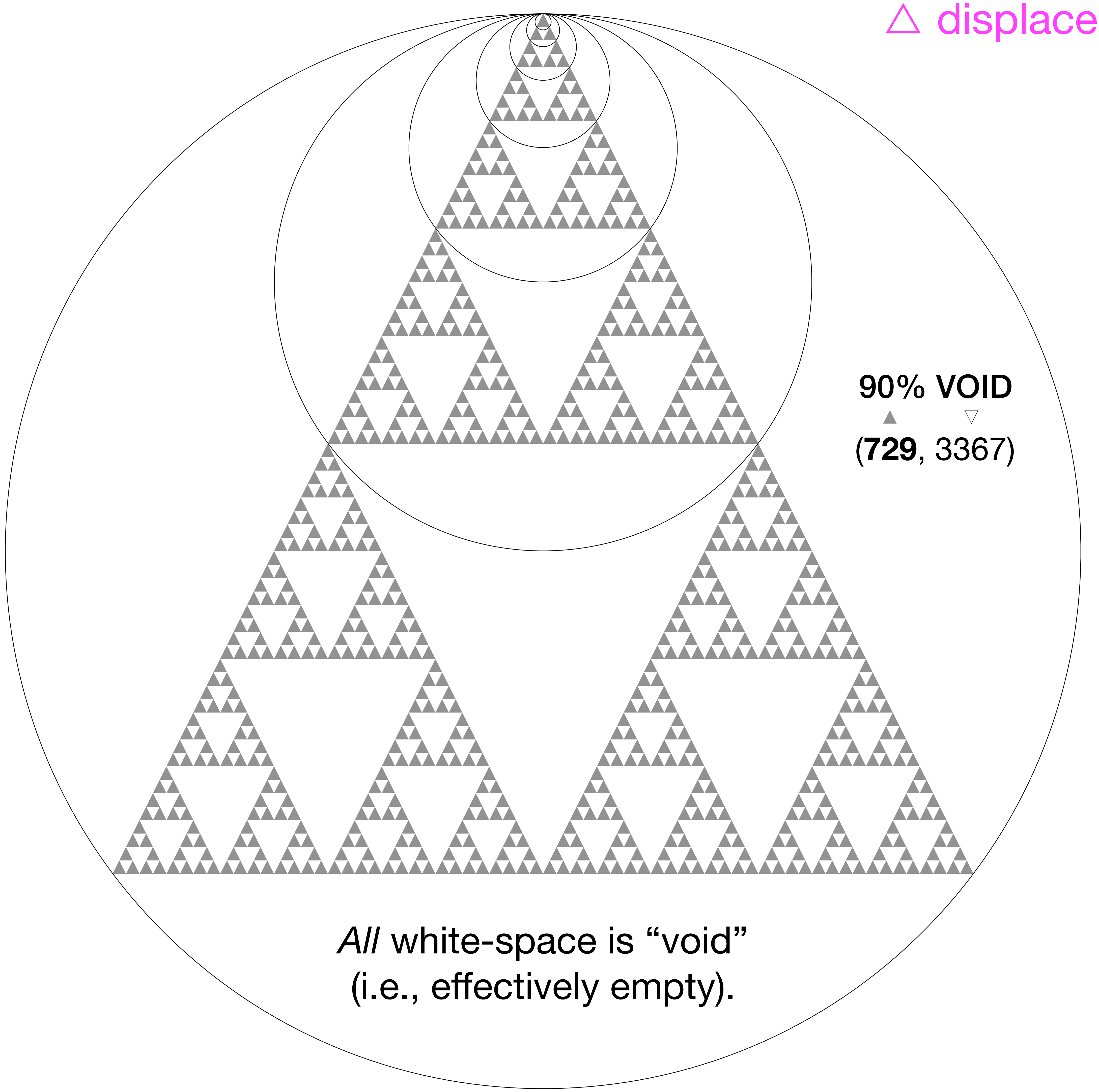
The 2dF Survey was conducted completely independently of the SDSS and in the southern hemisphere; the observed correlation of maxima and minima in redshift space seen in these data is then virtually certain to be empirical.

$\frac{dS^3}{dz} = C_{dV} \cdot \frac{4\pi}{\sqrt{1-(z+1)^{-2}}} \left[\frac{1}{(z+1)^2} - \frac{1}{(z+1)^4} \right]$
AGN (N ≈ 36k) $\Delta z_{bin} = 0.01$
SDSS (N ≈ 2.1M)
2dF (N ≈ 221k)
$C_{dV} = 102$
$\Delta z_{bin} = 0.0001$
variable dot-size for clarity
Redshift-bin galaxy count
800
600
400
200
0
0.01
0.1
1
Redshift (z)

amayer@alum.mit.edu • SensibleUniverse.net • Data: SDSS , NED , 2dF

Sierpiński triangle — a self-similar fractal

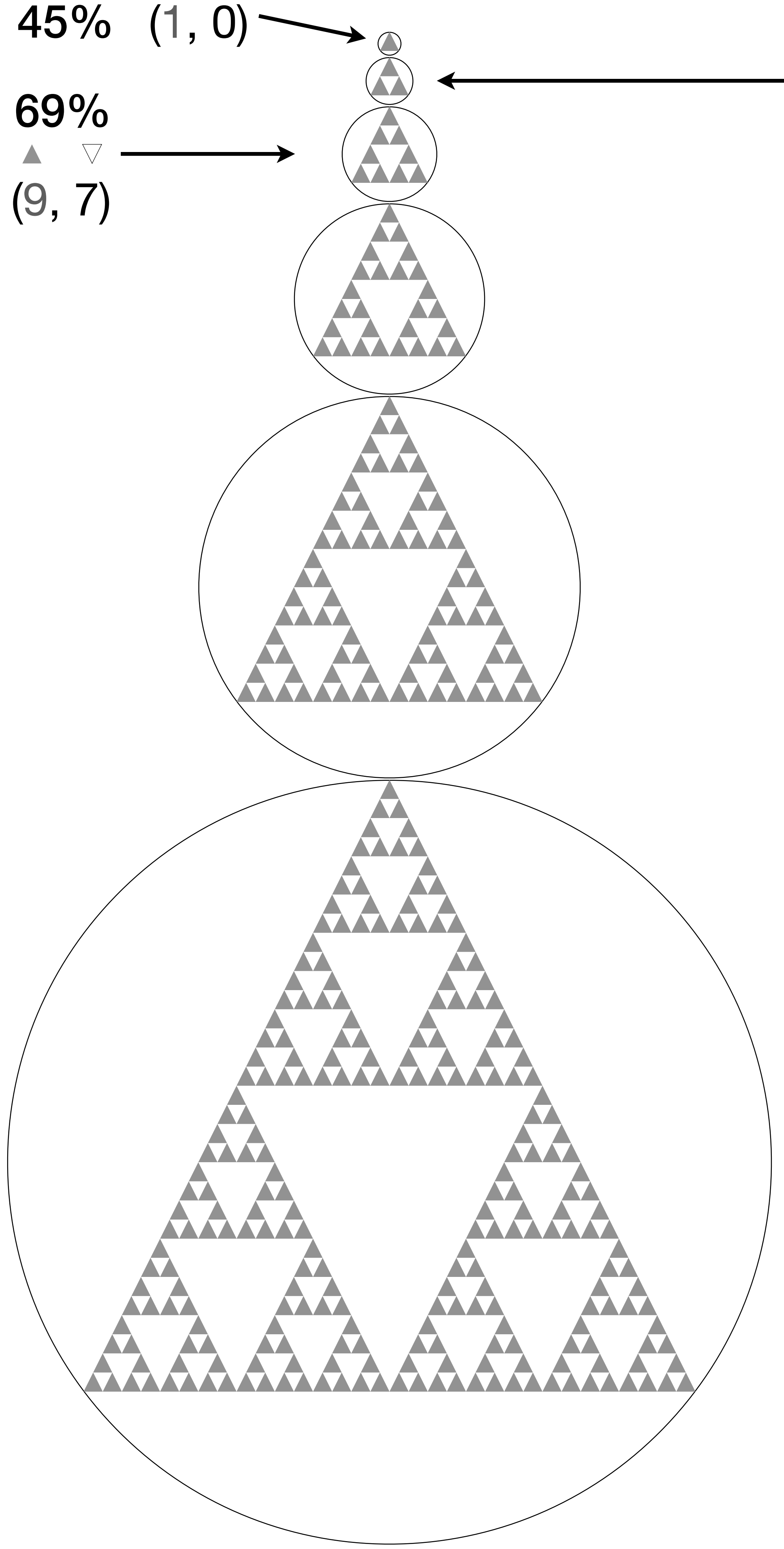
△ displaces ~55% of ○ $1-\frac{\sqrt{3}}{\pi}=$ **45%** ▲ ▽ (1, 0)



90% VOID
▲ ▽
(**729**, 3367)

All white-space is “void”
(i.e., effectively empty).

$$\%\ \text{VOID} = 1-\frac{\sqrt{3}}{\pi}\cdot\frac{729}{4096}$$



59%
▲ ▽
(3, 1)

69%
▲ ▽
(9, 7)

77%
▲ ▽
(27, 37)

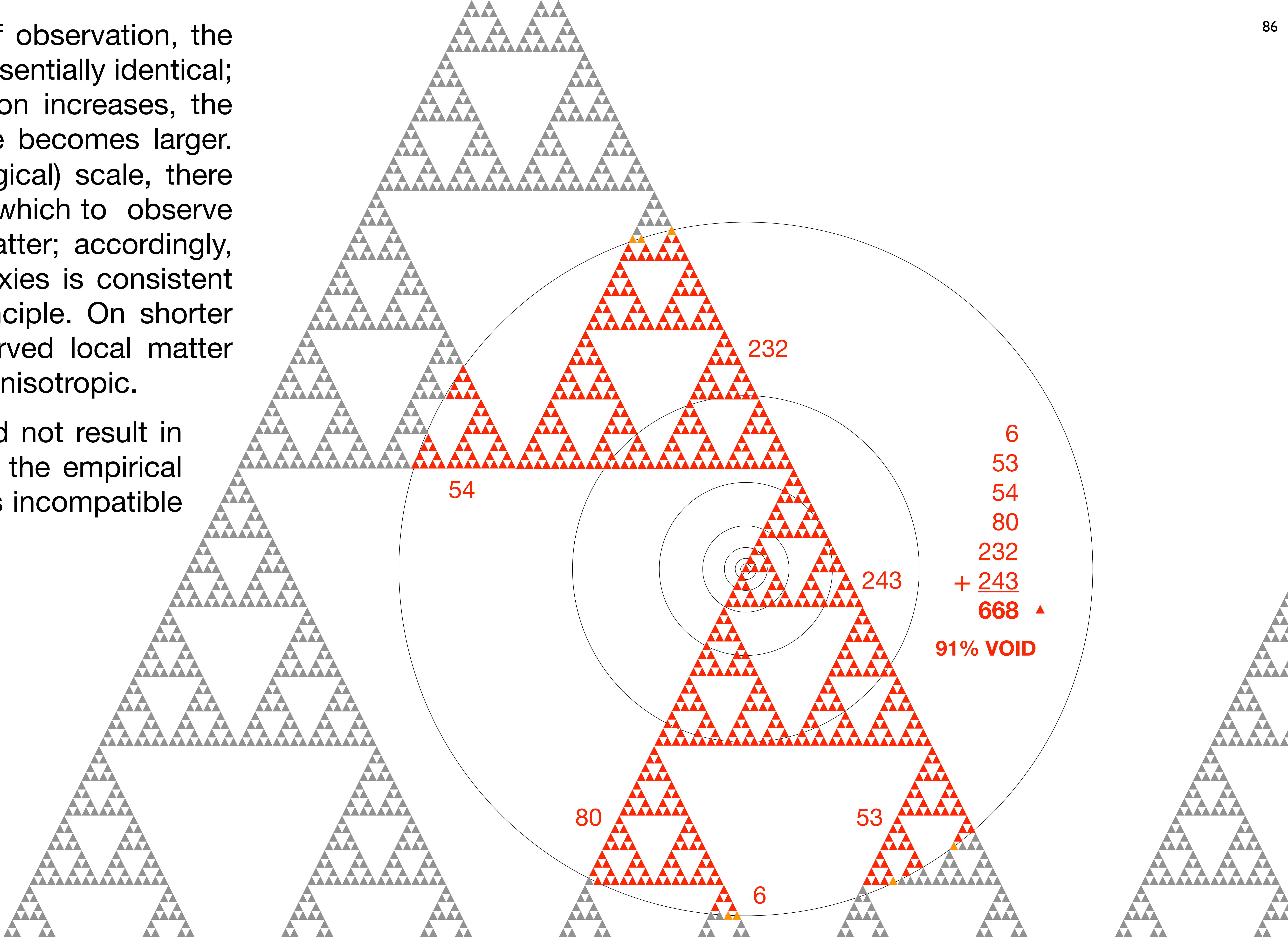
83% VOID
▲ ▽
(81, 175)

87%
▲ ▽
(243, 781)

The larger the observed region, the greater the proportion of empty space.

Regardless of the origin of observation, the pattern of observation is essentially identical; as the radius of observation increases, the proportion of empty space becomes larger. At *systemic* (i.e., cosmological) scale, there is no preferred origin from which to observe a fractal distribution of matter; accordingly, such a distribution of galaxies is consistent with the cosmological principle. On shorter distance scales, the observed local matter density may be decidedly anisotropic.

A uniform expansion would not result in such a matter distribution; the empirical data on pages 83 and 84 is incompatible with Big Bang cosmology.



Superclusters of galaxies - Fractal properties

Click for author info. Einasto, J. 🇪🇪

Results from a fractal analysis of observational data on the large-scale structure of the universe (Einasto and Einasto, 1988) are summarized. A plot of the mean diameter of voids found in surveys of galaxies and clusters of galaxies versus the corresponding sample sizes is presented, and it is found that a basic fractal property, the self-similarity of structures, has a lower limit defined by the mean diameter of galaxy clusters but no observationally based upper limit. It is inferred that the inhomogeneity of the universe extends to large scales, so that no available three-dimensional galaxy sample can be considered a fair sample; this finding is in agreement with Geller's (1988) conclusions from an analysis of redshift data.

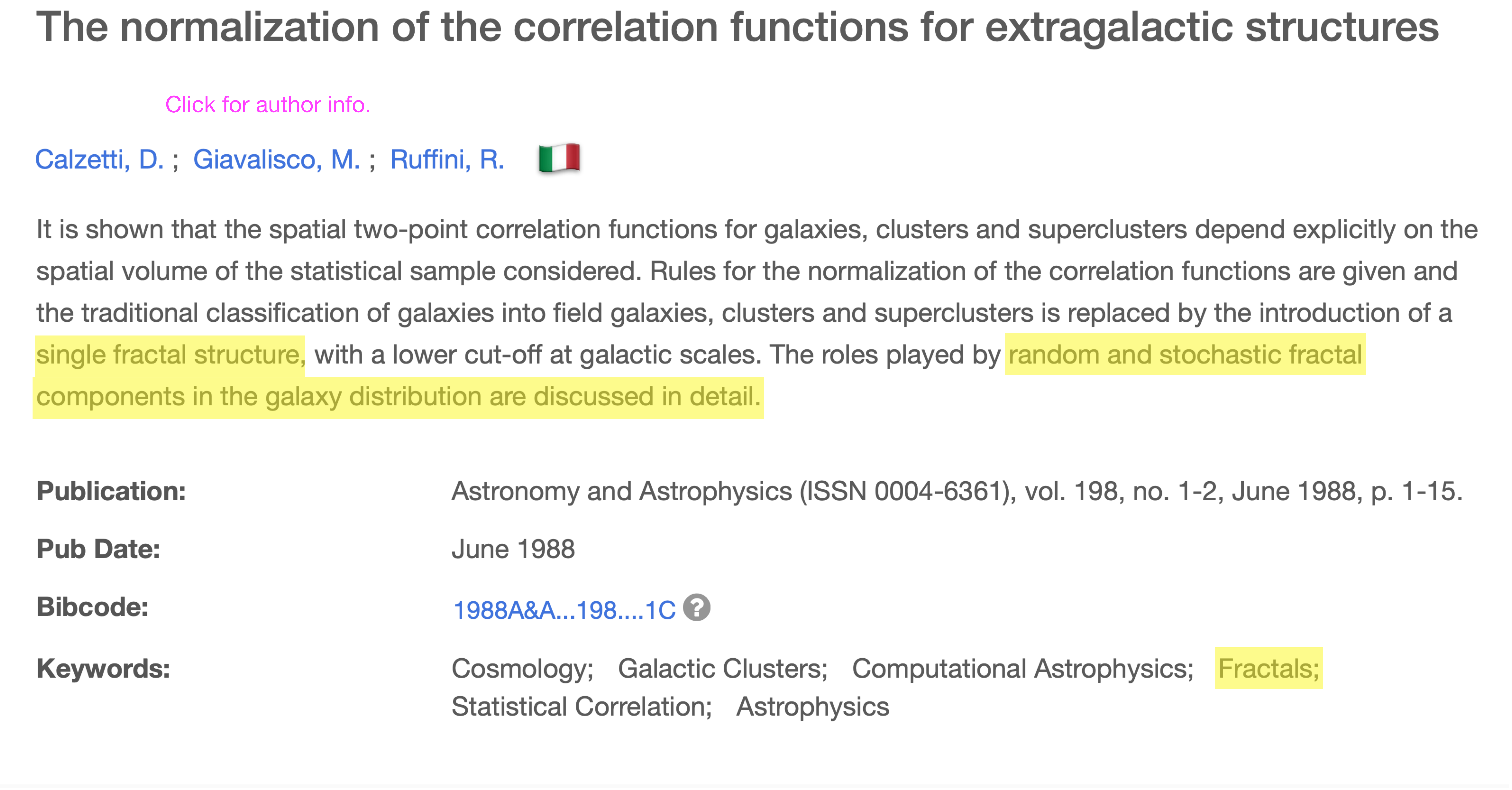
Publication: IN: Astronomy, cosmology and fundamental physics; Proceedings of the Third ESO-CERN Symposium, Bologna, Italy, May 16-20, 1988 (A90-44077 19-90). Dordrecht, Netherlands and Boston, MA, Kluwer Academic Publishers, 1989, p. 231-234.

Pub Date: 1989

DOI: 10.1007/978-94-009-0965-6_14

Bibcode: 1989ASSL..155..231E

Keywords: Cosmology; Fractals; Galactic Clusters; Spatial Distribution; Astronomical Models; Dark Matter; Galactic Structure; Astrophysics



The normalization of the correlation functions for extragalactic structures

Click for author info.

Calzetti, D. ; Giavalisco, M. ; Ruffini, R. 🇮🇹

It is shown that the spatial two-point correlation functions for galaxies, clusters and superclusters depend explicitly on the spatial volume of the statistical sample considered. Rules for the normalization of the correlation functions are given and the traditional classification of galaxies into field galaxies, clusters and superclusters is replaced by the introduction of a single fractal structure, with a lower cut-off at galactic scales. The roles played by random and stochastic fractal components in the galaxy distribution are discussed in detail.

Publication: Astronomy and Astrophysics (ISSN 0004-6361), vol. 198, no. 1-2, June 1988, p. 1-15.

Pub Date: June 1988

Bibcode: 1988A&A...198....1C ?

Keywords: Cosmology; Galactic Clusters; Computational Astrophysics; Fractals; Statistical Correlation; Astrophysics

SCIENCE • 16 Apr 1999 • Vol 284, Issue 5413 • pp. 445-446

PERSPECTIVES: COSMOLOGY

Is the Universe Fractal?

Vicent J. Martínez *It most certainly is!*

One of the fundamental issues in modern cosmology is the question of whether the spatial distribution of galaxies is homogeneous at a given scale. The cosmological principle, formulated originally by Einstein, states that the large-scale universe is spatially homogeneous and isotropic. It is this principle, together with Einstein's general relativity, that provides the theoretical framework on which the standard hot big bang model for the origin of the universe is based. However, the principle is an assumption and needs to be verified by observations.

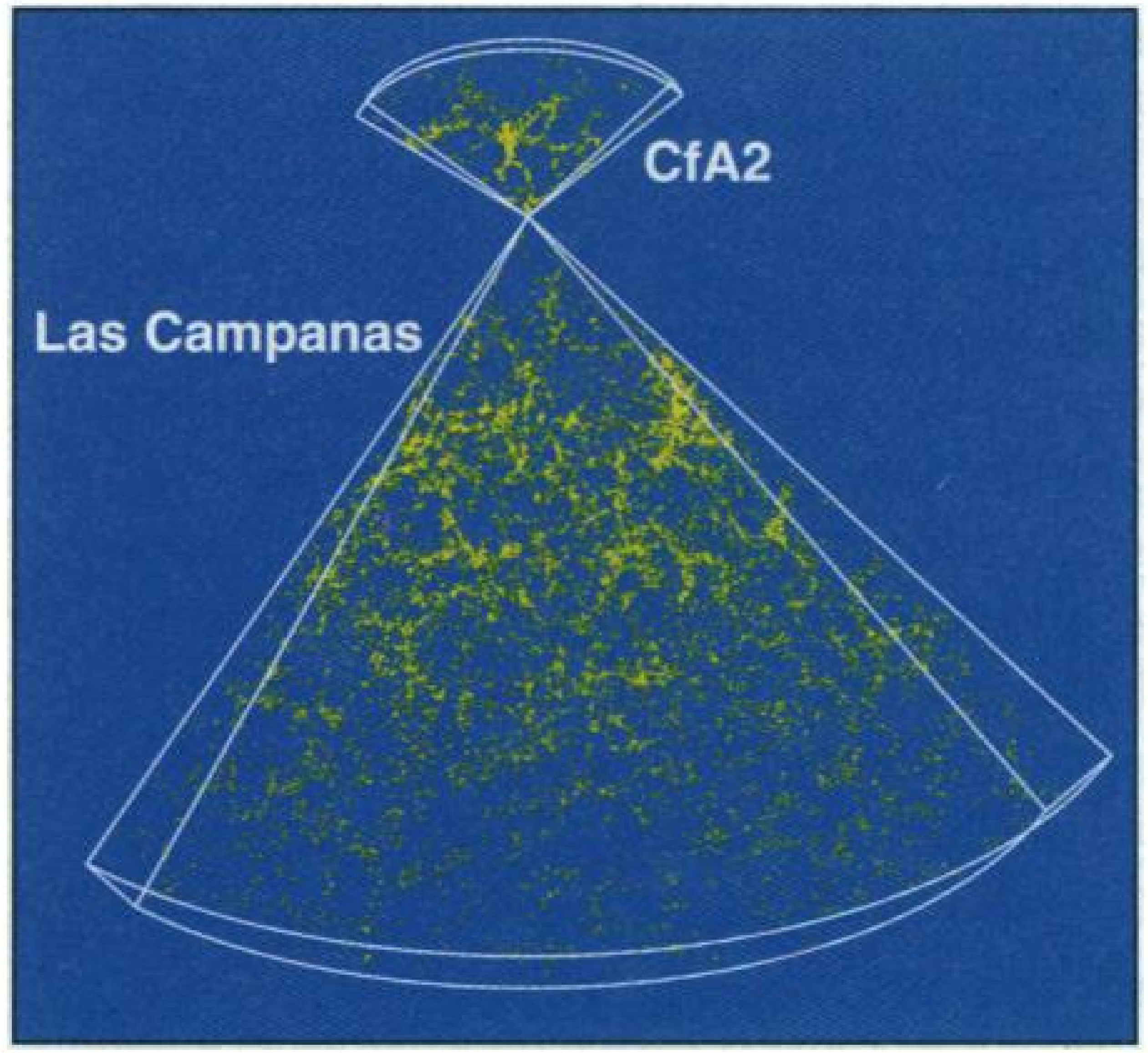
Enhanced online at www.sciencemag.org/cgi/content/full/284/5413/445

⋮

gest that homogeneity is being reached at larger scales.

The most popular tool for statistical analysis of redshift galaxy surveys is the two-point correlation function, $\xi(r)$ (*9*), which measures the clustering in excess [$\xi(r) > 0$] or in defect [$\xi(r) < 0$] compared with a Poisson distribution, for which $\xi(r) = 0$. In contrast, the correlation integral $C(r)$ (*10*) measures the average number of galaxies within a sphere of radius r of any given galaxy. In a fractal set, this function is proportional to r^{D_2}, where D_2 is the correlation dimension, one of the most common "fractal" dimensions used in the literature. For a uniform distribution, $C(r)$ is proportional to the volume of the sphere,

⋮

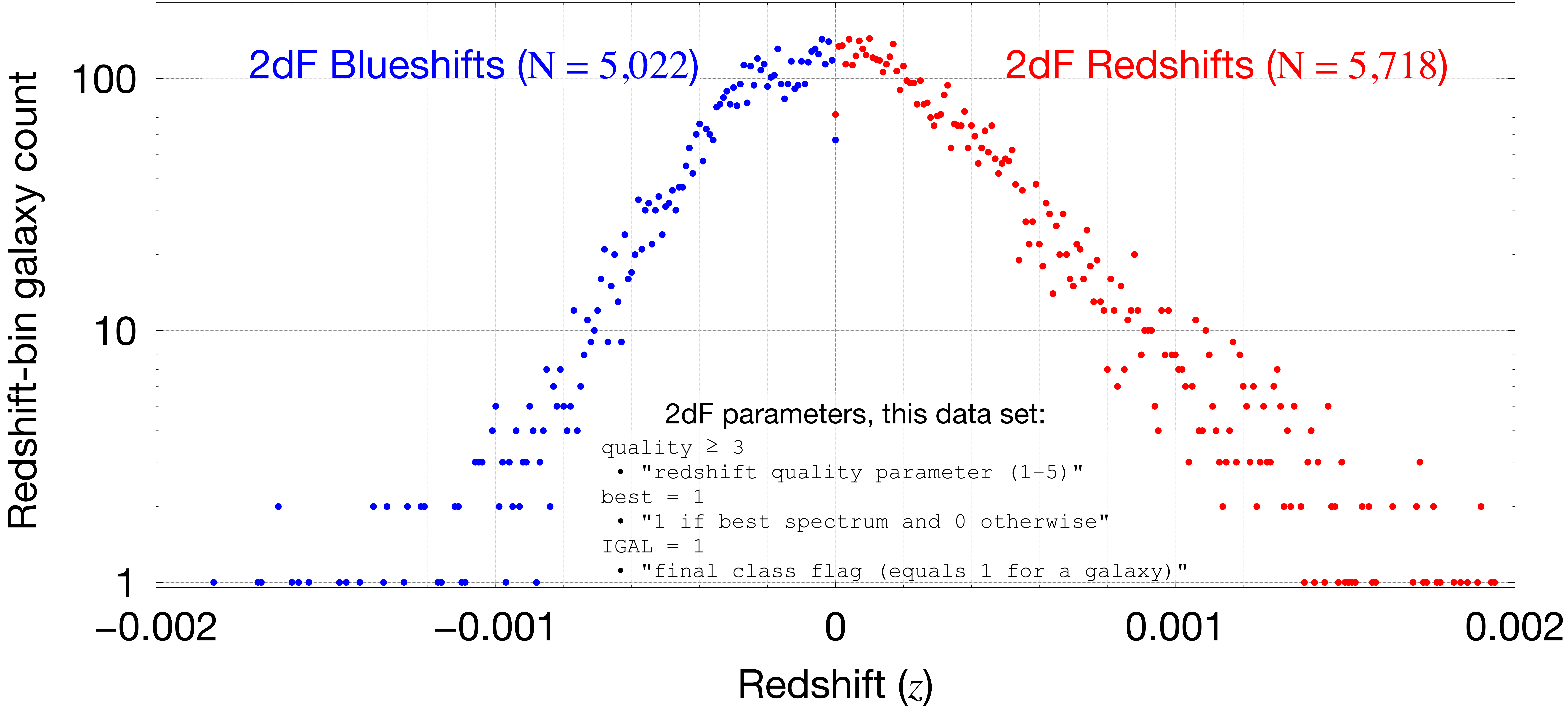


A matter of scale. The galaxy distribution for the southern slices of the Las Campanas redshift survey together with the first slice of the CfA2 catalog at the Northern Hemisphere. Although the depth of the Las Campanas slices is four times (in redshift) the depth of the CfA2 slice, the size of the structures is the same in both samples, contrary to what is expected for an unbounded fractal.

https://www.science.org/doi/abs/10.1126/science.284.5413.445

Approximately-equal numbers of galaxy redshifts and blueshifts

The rough symmetry between redshifts and blueshifts within a sample population of >10k galaxies in the nearby Universe $\left(|z| \leq 0.002\right)$ is indicative of random galactic velocities. This data is obviously inconsistent with the Big Bang paradigm of a general expansion.



2dF parameters, this data set:

```
quality ≥ 3
 • "redshift quality parameter (1–5)"
best = 1
 • "1 if best spectrum and 0 otherwise"
IGAL = 1
 • "final class flag (equals 1 for a galaxy)"
```

SDSS glossary reference

Magnitude, Petrosian

Stored as `petroMag`. For galaxy photometry, measuring flux is more difficult than for stars, because galaxies do not all have the same radial surface brightness profile, and have no sharp edges. In order to avoid biases, we wish to measure a constant fraction of the total light, independent of the position and distance of the object. To satisfy these requirements, the SDSS has adopted a modified form of the Petrosian (1976) system, measuring galaxy fluxes within a circular aperture whose radius is defined by the shape of the azimuthally averaged light profile. Details can be found in the Photometry section of the Algorithms pages and the Strauss et al. (2002) AJ paper on galaxy target selection. Model magnitudes share most of the advantages of Petrosian magnitudes, and have higher S/N; they are therefore used instead of Petrosian magnitudes for target selection in BOSS.

Source: https://www.sdss.org/dr14/help/glossary/#M

THE ASTRONOMICAL JOURNAL, 122:226–2280, 2001 November

SPECTROSCOPIC TARGET SELECTION FOR THE SLOAN DIGITAL SKY SURVEY: THE LUMINOUS RED GALAXY SAMPLE

DANIEL J. EISENSTEIN, JAMES ANNIS, JAMES E. GUNN, ALEXANDER S. SZALAY, ANDREW CONNOLLY, ET AL.

ABSTRACT

We describe the target selection and resulting properties of a spectroscopic sample of luminous red galaxies (LRGs) from the imaging data of the Sloan Digital Sky Survey (SDSS). These galaxies are selected on the basis of color and magnitude to yield a sample of luminous intrinsically red galaxies that extends fainter and farther than the main flux-limited portion of the SDSS galaxy spectroscopic sample. The sample is designed to impose a passively evolving luminosity and rest-frame color cut to a redshift of 0.38. Additional, yet more luminous red galaxies are included to a redshift of ∼0.5. Approximately 12 of these galaxies per square degree are targeted for spectroscopy, so the sample will number over 100,000 with the full survey. SDSS commissioning data indicate that the algorithm efficiently selects luminous ($M_g^* \approx -21.4$) red galaxies, that the spectroscopic success rate is very high, and that the resulting set of galaxies is approximately volume limited out to $z = 0.38$. When the SDSS is complete, the LRG spectroscopic sample will fill over 1 h^{-3} Gpc^3 with an approximately homogeneous population of galaxies and will therefore be well suited to studies of large-scale structure and clusters out to $z = 0.5$.

Key words: cosmology: observations — galaxies: clusters: general — galaxies: distances and redshifts — galaxies: elliptical and lenticular, cD — large-scale structure of universe — surveys

On-line material: color figures

z-band ($\lambda_{\mathrm{eff}} = 8887\text{Å} \approx 0.9\ \mu\mathrm{m}$) SDSS Petrosian magnitudes for ~870k galaxies

Note: JWST wavelength coverage is $0.6 - 28.5\ \mu\mathrm{m}$

As prior, color denotes data density, and the color scaling is logarithmic.

Selection Criteria:
Max. redshift error (SpecPhoto.zErr) ≤1%
Max. mag error (SpecPhoto.petroMagErr_z) ≤0.1 mag

Note: **SMALLER** astronomical magnitudes (mags) are **BRIGHTER**.

amayer@alum.mit.edu • SensibleUniverse.net • Data: SDSS

Distinguished subsample of ~136k targeted Luminous Red Galaxies (LRGs)

`CASE (legacy_target1 & 0x20) WHEN 0 THEN 0 ELSE 1 END AS fLRGsurvey`

SQL SELECT for flagging LRGs in SpecPhoto

z-band

D. Eisenstein et al.,
Luminous Red Galaxies in the SDSS (2004).

II. Introduction to SDSS LRGs

- SDSS uses color to target luminous, early-type galaxies at $0.2<z<0.5$.
  - Fainter than MAIN ($r<19.5$)
  - About 15/sq deg
  - Excellent redshift success rate
- The sample is close to mass-limited at $z<0.38$. Number density ~ $10^{-4}\ h^3\ \mathrm{Mpc}^{-3}$
- Co-conspirators: Annis, Connolly, Gunn, Nichol, Szalay
- Science Goals:
  - Clustering on largest scales
  - Galaxy clusters to z~0.5
  - Evolution of massive galaxies

LEGACY_TARGET1:

Bit Name	Binary Digit	Description
GALAXY_RED	5 [0x20]	Luminous Red Galaxy target (any criteria)

These galaxies were specifically selected to have similar characteristics, including their luminosity.

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Redshift-magnitude curves modeling constant intrinsic brightness

RTG:

$$m(z) = C_M - 2.5\log\left[\frac{1}{4\pi\left((z+1)^4-(z+1)^2\right)}\right] + \epsilon_\lambda \cdot \cos^{-1}\left(\frac{1}{z+1}\right)$$

$C_M = 14.82,\ 13.22 \quad \epsilon_\lambda = 0.5$

$C_M = 15.17,\ 13.57 \quad \epsilon_\lambda = 0$

ΛCDM:

$$m(z) = K_M - 2.5\log\left[\frac{1}{4\pi D_L^2}\right]$$

$K_M = -0.68,\ -2.28$

Data: ~136k SDSS LRGs (z-band)

intercepts
(0.32, 18.2)
(0.32, 16.6)

The data does not support this model.

The only ‘free parameter’ incorporated in the set of cosmological predictive equations on page 73 is the IGM-extinction parameter ε_λ. Although ε_λ is empirically a function of photon wavelength ($d\lambda/z$) the approximation of a constant value is reasonably accurate for other than very-high-z objects. The thin solid curves model $m(z)$ without taking extinction into account ($\varepsilon_\lambda = 0$). The thick solid curves employ an arbitrary choice of $\varepsilon_\lambda = 0.5$, to demonstrate its effect on the model.

Note: g-band data must exhibit 4000 Å break!

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According to the proposed predictive constant-intrinsic-brightness $m(z)$ curve in the previous page, the *statistical baseline* of the SDSS **z**-band redshift-magnitude data, which represents the *typical* brightest galaxies in the Universe, closely approximates (within a tolerance of about ±0.15 mag) what are called standard candles, or objects of nearly-identical *intrinsic* brightness. How can we *prove* this to be true beyond any reasonable doubt?

The 4000-angstrom break (D_{4000}) refers to a *drop* of about +1 magnitude in the apparent brightness of galaxies in the ultraviolet (i.e., **u**-band), as detailed on the following page. Elliptical galaxies, which are now understood to have formed by the merger of two or more progenitor spiral galaxies, and have populations typically exceeding 10^{12} stars, exhibit a strong 4000-Å break. Metals in the atmospheres of these older, cooler stars, for example, singly-ionized Calcium (Ca-II), absorb ultraviolet (UV) radiation.

For sufficiently distant galaxies, that well-known drop in flux of about one magnitude *redshifts* into the optical **g**-band. Observing the 4000-Å break in the *statistical baseline* of the SDSS **g**-band is then an empirical 'fingerprint', *proving* that the baseline of the data constitutes standard candles. If that were not the case—if the baseline of the redshift-magnitude data observed in the **g**-band represented a significant variation in intrinsic brightness—then the 4000-Å break would not be seen in that data (page 98).

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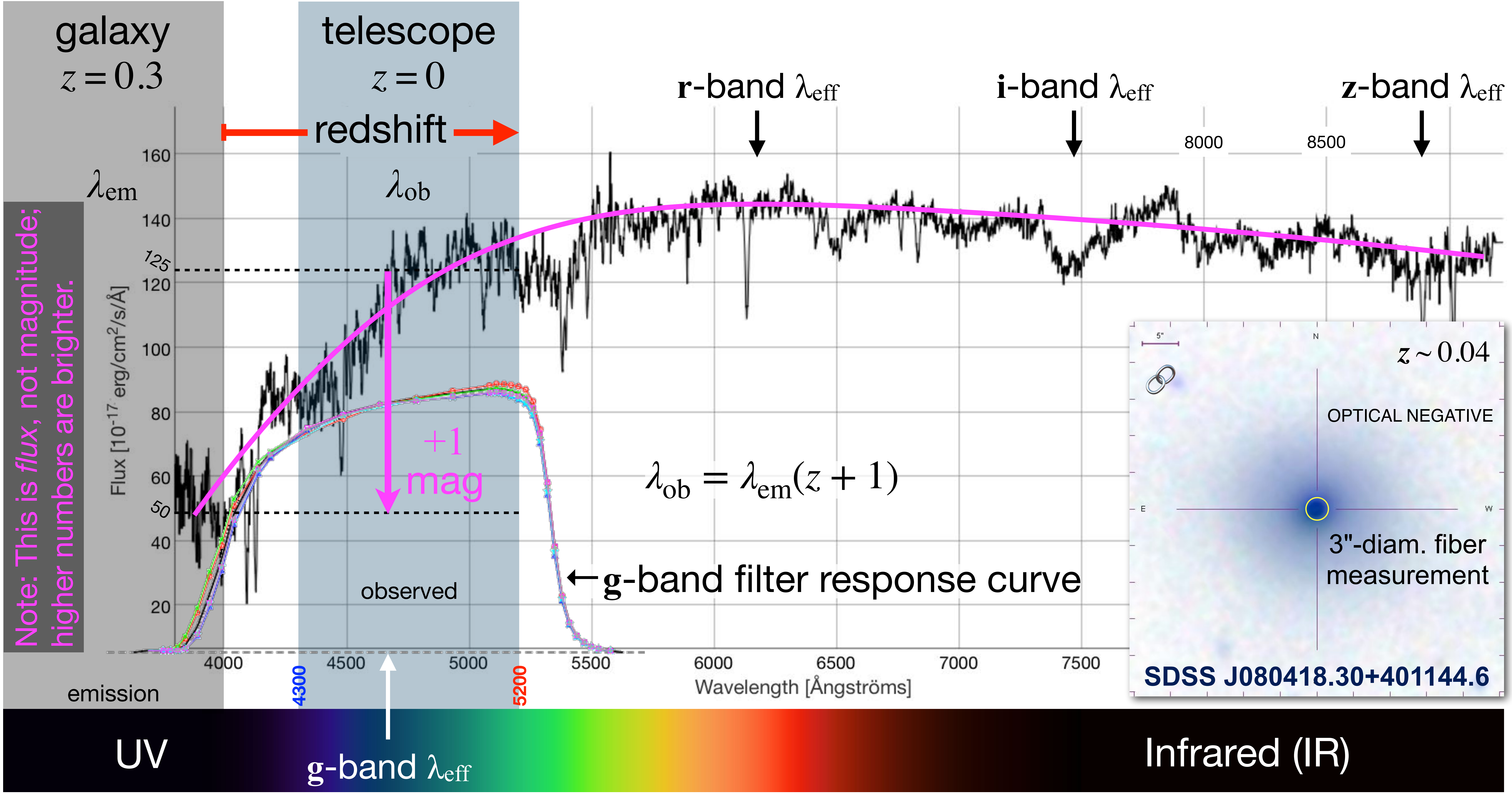
Galaxy spectrum demonstrating 4000-Å (Ca II) break



$$\lambda_{ob} = \lambda_{em}(z + 1)$$

Note: This is *flux*, not magnitude;
higher numbers are brighter.

```
15.09 - 2.5 * log10(1/(4 * 3.14159 * (pow((z+1),4) - pow((z+1),2)))) + 0 * acos(1/(z+1))
```

This and similar graphs were created using TOPCAT. Above is the actual function used to produce the **thin curve** of $m(z)$, as per Eq. 3 on page 73. $C_M = 15.09$ to intercept the base of the arrow, given an extinction factor of $\varepsilon_\lambda = 0$. The **bold curve** adds an extinction factor of $\varepsilon_\lambda = 0.25$ for comparison, with $C_M = 14.91$ to intercept.

g-band

In **g**-band data, empirical galactic standard candles must exhibit the 4000-Å break in relation to an accurate constant-intrinsic-brightness curve, which predictive model must delineate that same set of empirical galactic standard candles in the **z**-band.

Note that the **g**-band data is about 2 mags *dimmer* than for the **z**-band.
The magnitude-axis range here is 12–22 versus 10–20 for the **z**-band.

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Catastrophic Failure of the ΛCDM Model

IRREFUTABLE EMPIRICAL FACT: The Universe is *not* expanding.

A professional in the field who denies this fact is gaslighting: “Gaslighting is a form of psychological manipulation in which the abuser attempts to sow self-doubt and confusion in their victim’s mind. Typically, gaslighters are seeking to gain power and control over the other person, by **distorting reality** and forcing them to question their own judgment and intuition.”* They try to invalidate your own powers of reasoning — that is psychological malware.

*source: Newport Institute

Ignoring facts, *pretending* that they do not exist, is similarly abusive.

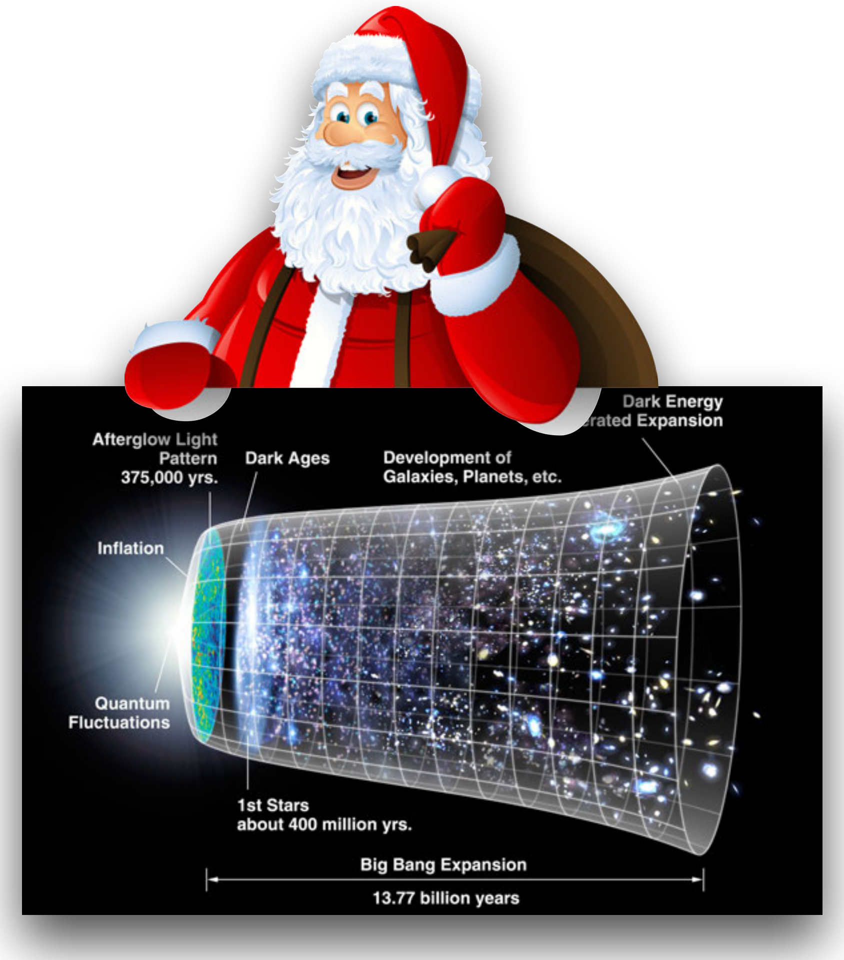
Download ADDENDUM
bit.ly/cosmo2023Add

All of the trusted ‘empirical evidence’ for the Big Bang theory that has appeared in the professional literature for nearly a century is Pathological Science at best, what Nobel Laureate Irving Langmuir (Chemistry, 1932) aptly called,

“the science of things that aren’t so.”

> “Now, cosmology is supposed to be the *Queen of the Sciences* because everything has to fit under that umbrella. But, if cosmology is wrong, misinformation is being fed down to all of the sub-disciplines and sub-sub-disciplines with the result that the thing, as I said, ‘Science is a mess.’ And you’ll notice also, common sense goes out the window immediately with the Big Bang.”
>
> – Wallace W. Thornhill (1942–2023)

JWST


Afterglow Light Pattern 375,000 yrs.
Dark Ages
Development of Galaxies, Planets, etc.
Dark Energy
rated Expansion
Inflation
Quantum Fluctuations
1st Stars about 400 million yrs.
Big Bang Expansion
13.77 billion years

Right now, the Big Bang theory is pretty much like Santa Claus:

"…you don't want your kid to be the *last* kid that figures out that Santa Claus is bullshit, because *that kid is a moron*."

Here, "kid" means students of cosmology, astrophysics, astronomy, physics, applied math, etc;
if you want to have a successful career in the field, you need to be dealing with *empirical reality*.

– Joe Rogan

"Because in academia, challenging conventional ideas gets you in deep shit. Even though we would like to believe that the [scientists] only base their opinions on data, that's not true. A lot of them have a long history of teaching things that eventually turn out to be incorrect, and they fight it tooth and claw." – J.R.

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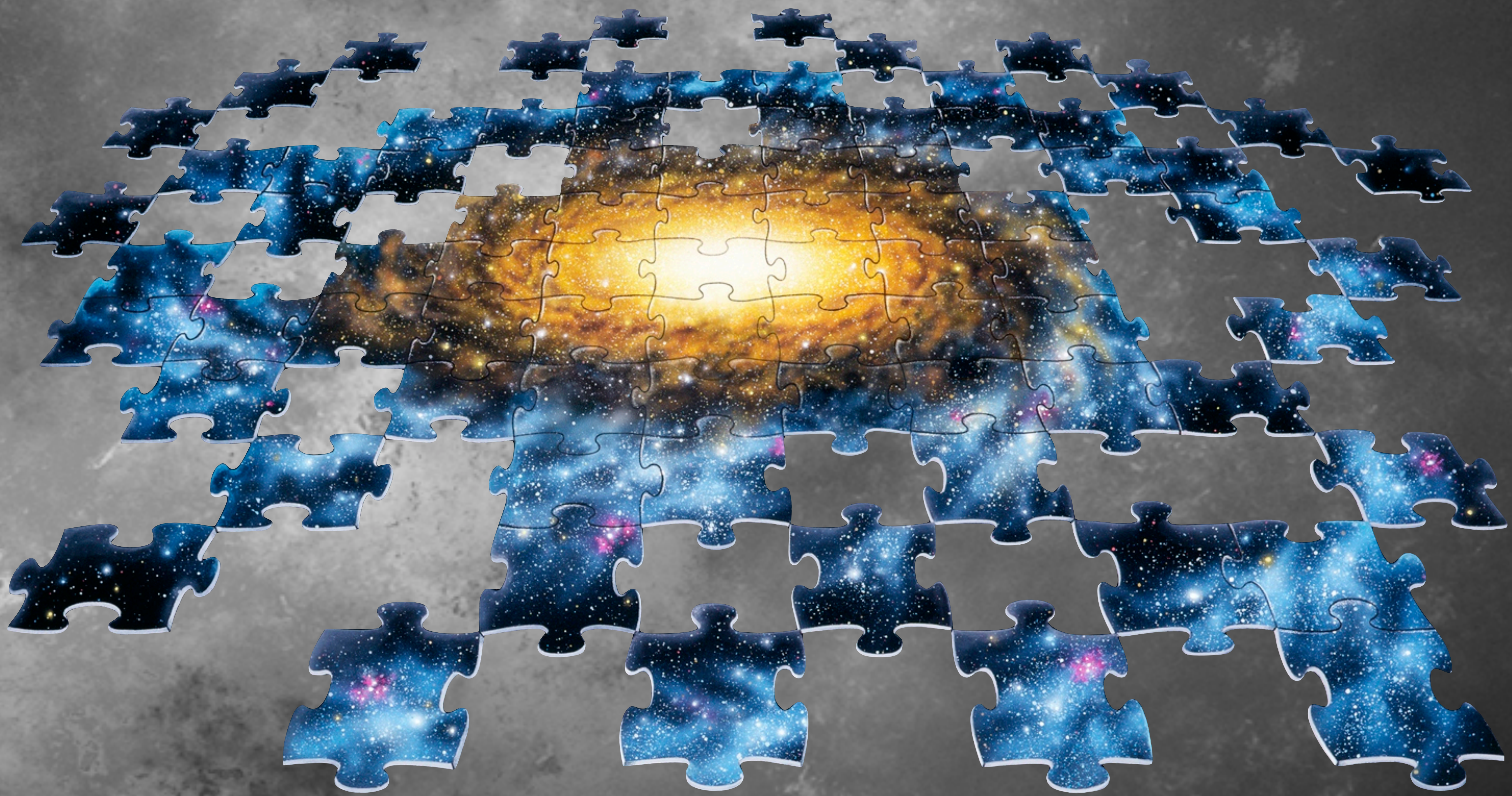
No ‘dark halo’: the effect of host cluster gravitational tidal forces on the internal dynamics of spiral galaxies

Alexander Franklin Mayer



15-minute video:

A new explanation of spiral galaxy rotation curves

(debunks ‘dark matter’)

“Le seul véritable voyage … ce ne serait pas d’aller vers de nouveaux paysages, mais d’avoir d’autres yeux, de voir l’univers avec les yeux d’un autre …” – Marcel Proust (1932)

“The real voyage of discovery consists not in seeking new landscapes but in having new eyes.”

29th Pacific Coast Gravity Meeting, UC Davis (3/30/13 16:15)

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> Creativity is the
> sudden cessation
> of stupidity.
> – Edwin Land

photo credit:
Alexander F Mayer (30 Aug 2020 • 16:18:08)
Patagonia Villa, Ushuaia, Tierra del Fuego, Argentina
SONY ILCE-6000 + E PZ 16-50mm F3.5-5.6 OSS
ISO 100   16 mm   0 ev   ƒ/8   1/200 s

Details will be provided in articles submitted to the *Astrophysical Journal*

Ethan Vishniac	Editor in Chief of *ApJ* and *all* AAS publications
Christopher Conselice	*ApJ* "Galaxies and Cosmology" corridor editor

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The *Astrophysical Journal* is devoted to recent developments, discoveries, and theories in astronomy and astrophysics. *ApJ* publications constitute significant new research that is directly relevant to astrophysical applications, whether based on observational results or on theoretical insights or modeling.

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Laguna Torre, El Chaltén, Santa Cruz Province, Argentina
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ISO 250 50 mm 0 ev ƒ/5.6 1/2000 s
Notes: Moon visible at 29° NNE @ 30° alt., 39.2% illum.

Transparency and detail are everything in science.
– Ben Goldacre

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Addendum

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View SW: The mountains are in Cabo de Hornos, Chile.

Reproducibility, closely related to replicability and repeatability, is a major principle underpinning the scientific method. For the findings of a study to be reproducible means that results obtained by an experiment or an observational study or in a statistical analysis of a data set should be achieved again with a high degree of reliability when the study is replicated.

⋮

Now, go here:

The term *reproducible research* refers to the idea that scientific results should be **documented** in such a way that their deduction is fully transparent. This requires a detailed description of the methods used to obtain the data and making the full dataset and the code to calculate the results easily accessible. This is the essential part of open science. – Wikipedia , “Reproducibility”

Software

TOPCAT
free

free

VEUSZ
free

NUMBERS

Data

SDSS
SkyServer

NASA/IPAC
Extragalactic
DATABASE